GRAPHIC REPRESENTATION OF SOLID OBJECTS

IN YOUNG CHILDREN

by

Margaret Jean Gatz

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Duke University

Date: July 5 1972

Approved:

Martin Lakin

Martin Lakin, Supervisor

Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor
of Philosophy in the Department of
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ABSTRACT

(Psychology-Clinical)

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This study traced in elementary school children the steps involved in acquiring the ability to represent a solid object graphically. Two samples of subjects--183 children from a neighborhood school in a lower socioeconomic, predominantly black area, and 82 children from a neighborhood school in a middle class white area--were individually administered a set of drawing tasks. Each child (a) drew a picture of a solid cube, (b) copied line drawings of both oblique and isometric projections of a cube, (c) copied forms characteristic of other subject's attempts to draw a cube (the Children's Cubes Scale), (d) copied angles and lines exemplary of the graphic elements which are included in a successful cube drawing, and (e) drew a complex configuration which was not a cube but which required all of the graphic elements and integrations involved in cube drawing.

The cube drawings were scored according to five stages: a square; a combination of squares; a figure which included diagonal lines; a figure which included parallel diagonal lines; a correct perspectival representation of a cube. These stages were hypothesized on the basis of Piaget's ideas about the

processes of spatial representation, Olson's work about acquisition of the ability to reproduce a diagonal line, and Lurcat's study about copying the oblique projection of the cube.

Three sets of hypotheses were tested. The first concerned the developmental sequence. The second explored the sequence of acquisition of graphic elements important to cube drawing. The third assessed the extent to which the ability to copy and to integrate graphic elements determined cube drawing ability at different grades and stages.

Examination of the drawings of the solid cube from children of different ages confirmed the hypothesized developmental sequence. This sequence was also attested to by the results of the Children's Cubes Scale, where the order of difficulty of the items replicated the stages of cube drawing. Socioeconomic and racial differences in the two samples did not affect the observed sequence, and subjects from both populations drew pictures of the solid cube at the same stages relative to their grade in school. However, for copying the various cube forms, the black lower class children did poorer than the white middle class children. Boys, on the whole, performed better than girls on the cube drawing tasks.

Results from copying graphic elements showed (a) that accuracy of angle copying is acquired in the order <u>right</u>, <u>acute</u>, <u>obtuse</u>, and (b) that parallel diagonal lines are more difficult to copy than parallel horizontal or vertical lines. The developmental stages of cube drawing reflect this same order of acquisition of graphic elements; however, children's accuracy on the elemental graphic tasks accounts very little for their level of cube drawing. Sex differences in cube drawing, on the other hand, were accounted for by differences between boys and girls in graphic abilities.

With reference to the last hypothesis, it was shown that, before they

were able to draw a cube, children could draw a correctly constituted configuration without being aware that they were drawing a cube. This result indicated that children's notions about how a cube ought to look actually may interfere with their objectively analyzing the visual input from cube stimuli.

Focussing on how children draw a single object, the cube, enabled analysis of the development and interdependence of representational processes and grapho-motor abilities. Taken together, the results of the three experiments suggested how children's central difficulty in drawing a cube varied as a function of the child's age and the dimensionality of the stimulus. An empirical enquiry like this one into a particular and yet representative problem of cognitive development is the first step toward solving such further theoretical and practical problems as establishing models of developmental change and determining useful and effective ways to instruct children.

ACKNOWLEDGMENTS

I wish to thank Dr. Martin Lakin, who has served as the chairman of my committee, for his patient and uncompromising efforts to make lucid both my writing and the thinking underlying it. He has invariably found time to talk to me and has repeatedly encouraged my efforts in doing this study. Most importantly, he consistently stressed the need for me clearly to formulate and present the goals, methods, and larger implications of this work.

I would also like to thank those other persons with whom I talked about this research at stages of formulation, data collection, and data analysis. Conversations with Dr. Lise Wallach and Dr. Marcel Kinsbourne were instrumental in establishing the experimental procedures used.
Dr. Mark Appelbaum advised me concerning statistical techniques to use in this study. Others who are or have been members of my committee also contributed many ideas--Dr. Philip Costanzo, Dr. Harold Schiffman, Dr. Lloyd Borstelmann, Dr. Richard Kramer, and Dr. Chris Crocker.

Dr. Byron Rubin has been a consistent source of support and assistance during this entire project. I am most appreciative to him for encouraging a scientific perspective and for spending hours with me discussing appropriate methodology for demonstrating cognitive phenomena. In addition, he contributed technical aid and advice, with such tasks as making the wooden blocks and taking photographs.

Essential to the project was the co-operation of the principals and teachers at the schools which participated in the pilot studies and in the present research. The principals were Mr. Lee Goode at Lyon Park School in

Durham, Mr. Spencer Wynne at R. N. Harris School in Durham, Mr. Frank Burnett at Pearson School in Durham, and Mr. A. D. Gaskin at T. Harry Garrett School in Augusta, Georgia. All of the teachers were remarkably tolerant of the disruption caused to their classrooms by the children's participation in this study. In particular, I appreciate the efforts of Mrs. LaVeta S. Campbell at Pearson School, who not only allowed all of her class to be tested but also was instrumental in making arrangements with other teachers in the school.

A Duke University Graduate School Research Award paid those who assisted with data collection and scoring, and covered the costs of equipment.

M. J. G.

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GRAPHIC REPRESENTATION OF SOLID OBJECTS

IN YOUNG CHILDREN

I. INTRODUCTION

Children who are just learning to talk are already able to look at pictures of objects and correctly associate them to the actual objects (Hochberg and Brooks, 1962). However, only after a lengthy period of development are children able to draw perspectival representations of three-dimensional objects, such as the cube. During the elementary school years, his attempts go through a series of changes. Studying developments which occur between recognition of the cube and its two-dimensional representation pertains to some general issues of cognitive development and to the developmental sequences in perception and representation. For a child to draw an object, he must have acquired perceptual recognition of the distinguishing features of the object, a conceptual system or representation of the object, and the requisite repertoire of motor skills. Changes in the way a child draws an object may indicate that he has accumulated more of the response elements required for the task, for example, greater graphic facility or a more differentiated perceptual schemata, or that he has changed how he conceptualizes the task of drawing the object. Focussing on a specific problem, in this case, reproducing the cube, is one approach to studying the complexity of relationships among several aspects of development. Taking cube drawing as an exemplary problem stimulates specific inquiry into how perceptual and conceptual structures are related, and what constitutes graphic complexity for a child.

Two normative questions arise: By what age does a child realize that the line drawing of a cube stands for the solid cube? By what age can

he draw the cube? Previous investigators differ in their answer to the former question. Hochberg and Brooks say that the association between solid object and two-dimensional representation can be made as early as nineteen months; Lurcat (1970) says that the association is not learned until the age of six or seven years. It seems probable that a child would learn the association between the solid cube and the drawing before he learned to draw a cube. Several investigators have demonstrated (Piaget and Inhelder, 1956; Olson, 1970) that with flat geometrical shapes there does exist a developmental time lag between ability to recognize and to reconstruct an item.

In answer to the question about the age at which a child learns to draw a cube, a survey of literature on cubes and other perspective drawing suggests that ability to draw perspective may not be acquired until about twelve years of age. Lurcat reports that 57 per cent of ten to twelve year olds can successfully copy a picture of a cube, and that by age thirteen or fourteen 95 per cent are successful. Rey (1947) found that drawing six cubes stacked in a staircase was too difficult a perspective task for nine to eleven year olds. Drawing a house involves a perspective problem similar to what is required to draw a cube. Leroy (1951) reports that ten to eleven year olds generally attempt to indicate perspective, but not until age twelve are over 50 per cent of them successful. Kerr (1936) found a lower prevalence of perspectival representation. She observed that less than 50 per cent of ten year olds attempted to draw houses in perspective, with 30 per cent of thirteen year olds successful in indicating perspective.

What makes drawing a cube a difficult task? One possibility is that the complexity of the configuration is the major difficulty and that the child lacks the requisite perceptual-motor skills to perceive and execute such a drawing. Alternatively, it could be that associating the solid object

with an appropriate two-dimensional representation is the problem. For example, with respect to the cube the conceptual difficulty may be that something which the child knows has square corners must be portrayed with diagonal lines. Theoretical and empirical studies relating to both of these explanations are outlined below, followed by the plan of this study.

The task of drawing a cube presents a complicated graphic problem, requiring integration of lines drawn in horizontal, vertical, and diagonal directions. An empirical study which elaborates on one particular way in which cube drawing might be difficult is Olson's work on children's acquisition of diagonality. He describes the peculiar difficulty which children have in constructing a diagonal line, and the relative ease with which they form a vertical or a horizontal line. Although Olson did not extend his study beyond the single line, it seems reasonable to expect that children would also have difficulty in combining diagonal lines to form acute and obtuse angles and in integrating these angles into complex figures, such as the cube. Thus, children might draw the cube with some or all of the diagonals replaced by horizontals or verticals, or with misdirected diagonal lines.

Previous empirical work concerning perspectival representations of cubes discusses developmental stages for drawings. However, in some studies the task was to draw a picture of a solid cube, while in others the task was to copy a line drawing of a cube. The implications of this difference in presentation was not attended to in these studies. In the present investigation both tasks were included, permitting discussion later on in this paper about the significance of the difference between a child's drawing a picture of a solid cube and his copying a line drawing of a cube.

Lurcat's work concerns copying the conventional line drawing of the cube, a task which she regards as purely perceptual-motor. The sequence she observed was (a) reduction to a quadrilateral; (b) orthogonal juxtaposition

of quadrilaterals (or an orthogonally partitioned figure); (c) a hybrid of juxtaposed faces with orthogonal and oblique sides; (d) the appearance of one parallelogram; (e) correct solution. Examples are shown in Figure 1.

Rey reports developmental stages for drawing multiple solid cubes. Young children often drew faces of two adjacent cubes as separated squares. (See Figure 2A.) Overall, children rarely indicated more than one face of each cube (see Figure 2B.), while older children might begin to suggest perspective. (See Figure 2C.) Rey discusses his results in terms of an interaction between difficulties of execution (i.e., perceptual-motor control) and difficulties of observation (i.e., discovery that form depends upon point of view), but his experiment does not contribute substantially to separating the roles of these two developments.

Some theories (Luquet, 1927; Piaget and Inhelder) about children's drawing describe developmental stages for the ability to draw objects. Preschool children, who are unable to integrate all the aspects of the object in the drawing of it, are said to be at the stage of "synthetic incapacity." This stage is followed by "intellectual realism," i.e., drawing the exemplary aspect or what is known about an object rather than what is seen. Lastly, children master drawing an object from a single point of view, "visual realism." Certain cube forms which would be consistent with these stages are illustrated in Figure 3.

Luquet attributes synthetic incapacity to grapho-motor immaturity and to limited and discontinuous attention. Once these abilities have matured, the child is able to draw a representation of the object. However, the child's drawing is not like a photograph of the object. He includes in his picture all elements which are true of the object, whether they are visible to him at that time or not, and he draws each detail in its characteristic form, e.g., plates on a table will be drawn as circles rather than

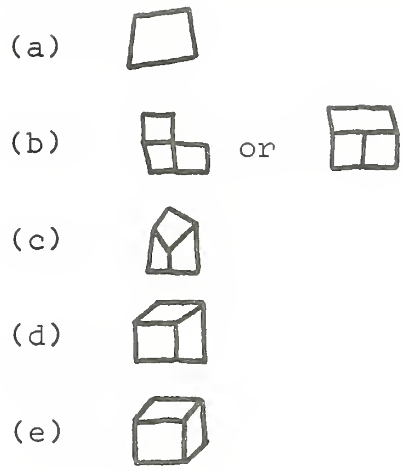


Fig. 1.--Stages of cube copying, from Lurcat

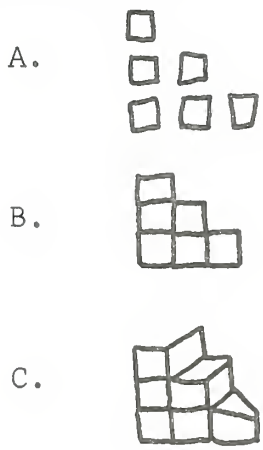


Fig. 2.--Stages of staircase drawing, from Rey

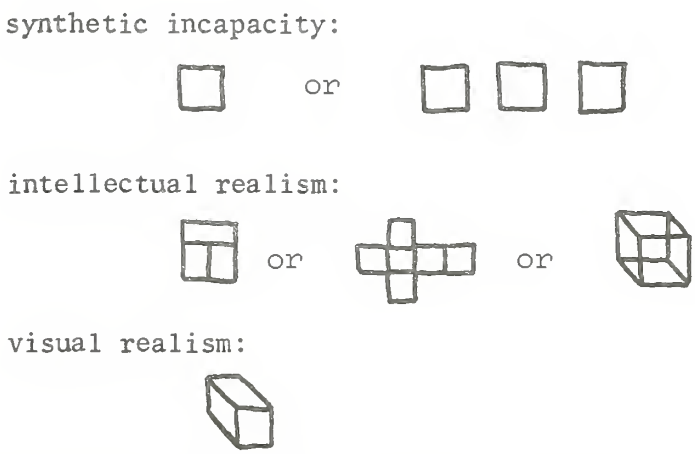


Fig. 3.--Hypothetical examples of Piagetian drawing stages

as ellipses, even though viewed from the side. According to Luquet, the explanation for these phenomena is that the child is not actually drawing a picture of the external object which is the subject matter of the drawing; he is copying his "internal model" of the object. A further implication of Luquet's construct is that in the stage of intellectual realism, difficulty in executing a drawing might imply that the child lacks an internal model for that particular object.

The concept of an "internal model" would appear to presage more recent experimental work about the mediating function of verbal labels. A verbal label is the name of a concept, or cognition, which corresponds to some category of stimuli, for example, "house," "square." Mediation, a cognitive process presumed to occur when a person is presented a stimulus object, may include not only (a) supplying an appropriate verbal label for the object, but also (b) cuing a set of actions with respect to the object (Wright and Kagan, 1963), e.g., drawing it.

The theoretical and empirical work reviewed above encompasses issues of perceptual-motor and conceptual development as they relate to the problem of drawing a conventional representation of an object. Olson's work suggests that there are elementary skills, essential to perspectival drawing, which may not be acquired until a child reaches a certain age. Luquet and Piaget and Inhelder focus on the cognitive steps involved in spatial representation, implying that perceptual-motor facility by itself cannot account for the development of a child's ability to draw a picture of a solid object.

II. STATEMENT OF THE PROBLEM

The purpose of this study is to inquire into the steps the child goes through in acquiring the ability to draw the cube. Specifically, I attempt to deal with the following three issues: (a) What are the steps between perceiving and representing the object? (b) In what order does a child acquire the specific perceptual-motor skills necessary for drawing complex geometric figures? (c) How does acquisition of strategies for combining the specific perceptual-motor skills contribute to the ability to draw the object?

The study as a whole is intended to explicate children's difficulties with cube drawing by demonstrating the simultaneous effects of various developments. However, the presentation of experimental hypotheses, procedures, and results is facilitated by separating the various questions. In the remainder of this section three experiments are introduced, corresponding to the three issues.

A. Experiment 1

What are the steps between perceiving and representing the object? In order to demonstrate that the different cube drawings represent distinct developmental stages, one must show that there are qualitative differences between the proposed steps, and that children can draw cubes characteristic of lower but not of higher stages. Evidence such as positive correlation of stages with chronological and mental age would lend support to the argument that the steps are developmental.

Based on the theoretical and empirical work reviewed above, a series of hypotheses is proposed.

Hyp_1: There are standard stages of cube drawing among children.

Hyp_2: Acquisition of the ability to copy a drawing of a cube also occurs in stages.

Hyp_3: The developmental sequence, regardless of age, is

1. the tendency to draw a square,
2. the tendency to draw juxtaposed or perpendicularly subdivided squares,
3. the tendency to draw a figure with three parts, predominantly using right angles but including some diagonal lines,
4. the tendency to draw figures containing parallel lines in three directions,
5. the tendency to draw the conventional perspectival cube.

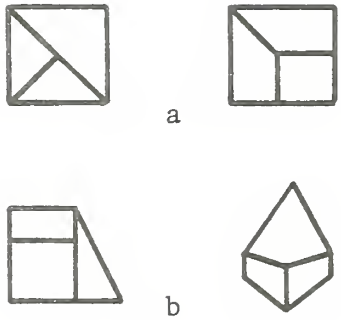
These hypothesized stages of cube drawing are based on an amalgam of the research of Olson, Lurcat, and Luquet. The early stages are consistent with Luquet's theory as well as with Lurcat's results. Due to Olson, incorporation of diagonal lines and non-right angles into cube drawings is predicted to be a late development. Finally, following Lurcat, parallelism is predicted to be the last component skill which must be acquired.

Thus, the hypothesized stages, illustrated in Figure 4, represent a progression of drawing skills. In the first two stages, while the number and the relative placement of faces varies, only horizontal and vertical lines are used to draw the pictures. A single quadrilateral is called stage 1 (see Figure 4.1). Figures with a square outline, subdivided by orthogonal lines, are referred to as stage 2a. Figures made up of a juxtaposition of squares are called stage 2b (Figure 4.2). In stage 3 diagonal lines appear in addition to horizontal and vertical lines. These lines may be used to divide the interior of a square into a number of parts, generally three parts with each part adjacent on some border to each of the other two

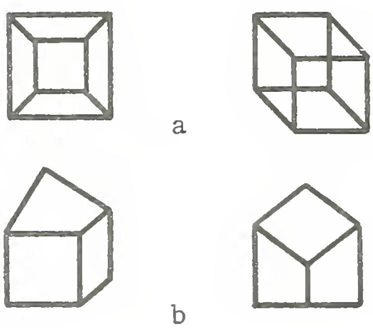
1. the tendency to draw a square

2. the tendency to draw juxtaposed or perpendicularly subdivided squares

3. the tendency to draw a figure with three parts, predominantly using right angles, but including some diagonal lines



4. the tendency to draw figures containing parallel lines in three directions



5. the tendency to draw the conventional perspectival cube

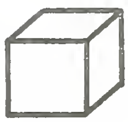


Fig. 4.--Hypothesized stages of cube drawing

parts, which figures are referred to as stage 3a. Stage 3b figures are made up of a number of polygons, usually three, of various shapes. The outline of these figures is never square, implying that at least one angle which is not a right angle must have been drawn in the course of drawing the figure (Figure 4.3). By stage 4 a child is able to draw diagonal lines parallel to each other, and to draw obtuse angles. Transparent figures, e.g., Necker cubes, are called stage 4a; other stage 4 figures are called stage 4b (Figure 4.4). A stage 5 perspectival cube drawing requires either (a) that three lines be parallel to each other in each of three directions (as in Figure 4.5), or (b) that rules of point perspective be followed such that any set of three lines converges toward a single distant point.

In terms of graphic skills, there is little evidence to suggest a sequential relationship between stages 2a and 2b. Although Lurcat also would make no particular distinction between stages 3a and 3b, it would seem that a stage 3b drawing requires more skill at manipulating diagonal lines. Making a stage 3a drawing less frequently requires that the child construct non-right angles, because each of the diagonal lines often connects two points which are already drawn. A similar argument would lead to the suggestion that stage 4b would follow stage 4a. These more refined sequences are explored after testing for the five hypothesized stages.

B. Experiment 2

In what order does a child acquire the specific perceptual-motor skills necessary for drawing complex geometric figures? As previously discussed, the task of drawing a cube may involve perceptual-motor and conceptual problems. In this experiment and the next we shall view cube drawing as a perceptual-motor problem of acquiring and integrating a number of component graphic skills. In order to progress through the hypothesized

developmental sequence of cube drawings, a child must be able to execute right, acute, and obtuse angles, and parallel lines. There are other graphic skills essential for drawing complex figures, such as accurately reproducing the length of a line segment, and drawing three or more lines such that they come together at a single point. I chose to focus on angles and parallel lines because of their relevance to the cube drawing sequences of Luquet, Rey, and Lurcat, and because the study of these particular skills follows and extends the work of Olson.

Olson demonstrated that children have more difficulty constructing a diagonal than a vertical or a horizontal line. Orthogonal lines might be easier because they can be guided by the edges of the paper (Piaget and Inhelder), or it may also be that horizontal and vertical lines and right angles are what are most frequently encountered in our culture (Segall, Campbell, and Herskovits, 1963). Along with this experience, Olson suggests that the motor act of drawing a right angle might be acquired sooner than the ability to draw any other angle, and that children might represent other perceived intersections as right angles because right angles were the only angles which they had learned to draw. However, Olson neither tests these hypotheses nor answers the following questions related to angle acquisition. At what age does a child learn to draw non-right angles with some degree of accuracy? How refined is his ability to discriminate differences among angles? Following the line of argument of Segall, Campbell, and Herskovits, it might be speculated that experience with acute angles would occur prior to experience with obtuse angles, because acutes are found in alphabetic letters (A,V) and in pointed objects such as an arrow or a rocket. Hence, a developmental sequence would be hypothesized, with mastery of angles occurring in order from right to acute to obtuse. Such a sequence of angle mastery would be observable in a child's copies of angles by themselves and in his copies of

figures containing these angles.

A second hypothesis related to Olson's study is that drawing parallel diagonal lines would be more difficult than drawing two horizontal or vertical lines parallel to each other.

It is therefore hypothesized that

Hyp_4: acquisition of the ability to draw angles occurs in the sequence right, acute, obtuse;

Hyp_5: there is a developmental sequence for drawing parallel lines, namely, that horizontals and verticals precede diagonals;

Hyp_6: sequences observed for isolated lines and angles are observed for the same lines and angles within a complex configuration.

C. Experiment 3

In Experiment 1, stages for describing how children approach the task of drawing a cube were developed. The task of drawing a picture of a solid cube encompasses both perceptual-motor and conceptual problems. In Experiment 1, the child's task is to apprehend, conceptualize, and represent the object graphically.

In Experiment 2, the acquisition of two different graphic skills, each of which is an ability relevant to the task of drawing the conventional representation of a cube, was investigated. The results of Experiment 2 suggest the extent to which the motor skills required to draw a cube are movements of which the child is capable. In other words, these experimental results describe the child's efforts to draw a cube in partial, piecemeal form.

Cube drawing, however, requires more than correctly copying an angle of a particular size, or being able to draw three lines such that they meet at a single point, or drawing two parallel lines of the same length but with staggered ends. The child also must combine all of these elements, by

deciding which line or angle to draw first, whether to complete the outline before drawing any lines inside, whether to draw as a set the lines that are parallel to each other. This is the second part of the graphic task, the strategic part.

It is a difficult experimental problem to study these strategic problems without involving the hypothetical conceptual problems. One way is to have children draw a design which is exactly as complicated in all of its graphic attributes as a cube is, but which is not a cube. It would further be desirable if this new design were not perceived as representing three-dimensionality. Then, if the children's performance on the new design was significantly better than their cube drawing, it would appear that there was a conceptual problem which interfered with drawing a cube, namely, having to draw in two dimensions a picture which represents three dimensions. It would further appear that mastery of this conceptual problem lagged behind mastery of the requisite graphic skills and combinatorial strategies.

Devising a design equivalent to the cube but with no implicit three-dimensionality is not readily achieved. Accordingly, the mock-cube was invented. This is a flat wooden block, shaped like a hexagon, with lines painted from alternate corners to the center (see object in lower right-hand corner of Plate 1). The mock-cube is a successful stimulus for the experiment proposed, because it is not perceived as a cube or as representing a cube. Yet, drawing it requires graphic abilities and integrations identical to what is required to draw a cube.

In this experiment, how a child draws the mock-cube is compared to how he draws a cube. A number of different outcomes are possible. (a) If the mock-cube is drawn well at a younger age than the children can draw a solid cube, this is evidence of a deficiency in the conceptual knowledge necessary for the child to translate from seeing the solid cube to knowing what

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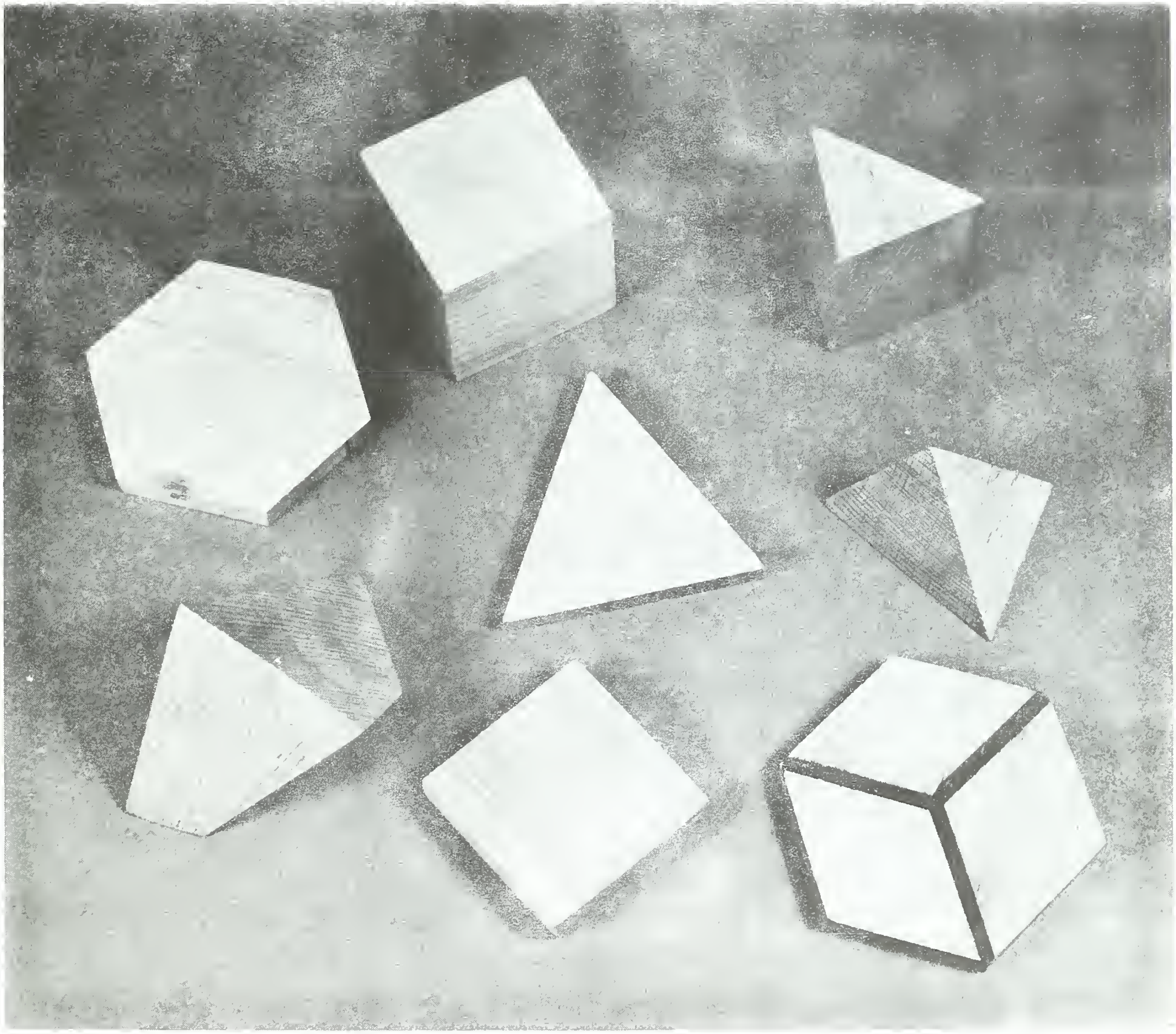

PLATE 1

The Wooden Forms

he should draw. (b) If a child draws the mock-cube better than he can copy two-dimensional projections of the cube, this suggests cognitive interference, of the following sort. The association of the two-dimensional picture with the notion of a solid cube leads the child to copy the two-dimensional picture in the same way as he would draw a solid cube, such that the same problems of representation of three dimensions on to two-dimensional paper would occur for the task of copying the two-dimensional design as for the task of drawing the solid cube itself. (c) If the mock-cube, the solid cube, and the cube projections are drawn equally as well, then purely grapho-motor explanations should be sought for the forms which appear. (d) If the mock-cube is drawn less well than the solid cube, then this experiment would be inconclusive as concerns the role of conceptual difficulties in cube drawing.

Insofar as part of the difficulty with drawing a solid cube is expected to be conceptual, it is hypothesized that

Hyp_7: children can successfully draw a mock-cube (and hence unintentionally draw a cube) before they perform equally as well on the task of drawing a picture of a solid cube.

III. EXPERIMENTAL PROCEDURES

A. Experimental Design

Data from two different samples of children were separately collected and analyzed. This procedure permits post hoc hypotheses derived from the first set of data to be tested on the second sample. Each child participated in the entire protocol of drawing and matching exercises, which are outlined in Part C. of this section. The order of presentation of the tasks was systematically varied, in a modified Latin square design, in order to control statistically for any effects which one task might have on the performance of another. The eight different experimental sequences which were used are listed in Appendix A. Each child was individually tested either by the experimenter or by an assistant.[1] The entire protocol required from twenty to fifty minutes, depending upon the child's ability and work habits.

B. Subjects

Approximately thirty children from each grade, first through sixth, were seen in W. G. Pearson School in Durham, North Carolina, and approximately thirty children from first, third, and fifth grades were seen in T. Harry Garrett School in Augusta, Georgia. The North Carolina sample was predominantly comprised of black children with parents in the lower socioeconomic levels; the Georgia sample consisted of white children, for the most part from middle-class homes.

Demographic data for the Pearson School subjects are presented in

[1]The experimenter acknowledges the assistance of Svea Oster Katz and of Mrs. Arthur J. Gatz with the data collection. Without their help, the length of time required to collect the data would have been prohibitive.

TABLE 1

PEARSON SCHOOL SUBJECTS

Grade	Number of Subjects	Av. Age at Time of Testing	% Black	% White	% Male	% Female	Av. IQ
1	30	7 yr. 0 mo.	90	10	53	47	Average Lee-Clark Reading Readiness score=43 (low av.)
2	30	8 yr. 2 mo.	93	7	37	63	Average Lee-Clark Reading Readiness score=42 (low av.)
3	30	8 yr. 9 mo.	97	3	50	50	96 (Otis)
4	32	10 yr. 0 mo.	97	3	62	38	92 (Otis)
5	[illegible]	[illegible]0 yr. 6 mo.	93	7	39	61	103 (Otis)
6	30	12 yr. 0 mo.	93	7	47	53	94 (Otis)

TABLE 2

T. HARRY GARRETT SCHOOL SUBJECTS

Grade	Number of Subjects	Av. Age at Time of Testing	% Black	% White	% Male	% Female	Av. IQ
1	23	6 yr. 9 mo.	0	100	43	57	Not tested until after the first grade year
3	29	8 yr. 9 mo.	0	100	48	52	112.59
5	30	11 yr. 1 mo.	0	100	53	47	104.63

Table 1.[1] The mean IQ for these students (based on the Otis Quick Scoring IQ measures and the Lee-Clark Reading Readiness Test) was 95. The children tended to come from families with an average of four or five children. About half of the fathers listed laborer as their occupation. Only twelve per cent of the fathers were high-level technicians or professionals. The average number of years of education obtained by both fathers and mothers of these children was eleven years.

Comparable demographic data for the T. Harry Garrett School subjects are shown in Table 2.[2] The mean IQ for these students was 109. The children tended to come from families with an average of three children. Sixty-seven per cent of the fathers held a white-collar (technician or managerial) or professional job.

The Pearson School subjects were seen over a two-month period of time, beginning with the third grade in mid-December, and continuing from after Christmas vacation through early February with the other grades in the order fourth, fifth, sixth, second, first. The T. Harry Garrett School subjects were all tested during one week in February.

C. Tasks

Children were taken from their classroom to the testing room, where they were seated at a desk or table, with the experimenter sitting on the left. The experimenter presented the tasks one at a time, sequentially using each of the experimental sequences from Appendix A. The procedures for the separate tasks are presented below in an order which corresponds to the three experimental issues.

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[1] The experimenter acknowledges the assistance of Myrna Brake in collecting this information from the Pearson School records.

[2] Mrs. Jan Crickenberger helped to obtain this information from the T. Harry Garrett School files.

First, what are the steps between perceiving and representing the object?

1. Cube Matching

These tasks were designed to demonstrate whether a child had acquired the association between the solid cube and the perspectival line drawing of it. Recognition that the line drawing is a picture of the solid cube was tested in two ways. In the first instance, the child was shown a page containing fifteen drawings of cubes which were representative of the entire range of children's attempts to draw a cube (see Figure 5). The experimenter said, "Look at all of these pictures," gesturing to encourage the child to look over the entire page. Then the child was given a solid cube and asked which one of the pictures was the best drawing of it.

On the second test, the child was given a drawing of a cube and asked to match the drawing to the object it pictured. The objects included solid wooden blocks (cube, triangular solid, tetrahedron, and irregular seven-sided solid) and flat wooden forms (square, triangle, hexagon), as shown in Plate 1. The child's correct choice demonstrated that he could associate the shape of the object with the figure. To indicate whether both drawings of the cube had the same meaning, the child performed the task for both the oblique and the isometric projections.[1] These were interspersed among other pictures (perspectival representations of a triangular solid [see Figure 7A] and a tetrahedron [see Figure 7B], and drawings of a square, a triangle, and

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[1]Throughout this study three cube stimuli are used, a solid cube and two different perspectival line drawings of a cube: (a) The <u>cube</u>, a three-dimensional object, is operationally a wooden block. The task of drawing this stimulus may be called cube drawing. Both (b) the <u>oblique projection</u> of the cube, which is sometimes called the conventional representation of the cube (shown in Figure 6A), and (c) the <u>isometric projection</u> of the cube (shown in Figure 6B) are two-dimensional representations of the solid cube, i.e., projections of the cube on to a plane. The task of drawing either of these two stimuli may be called copying a picture of a cube.

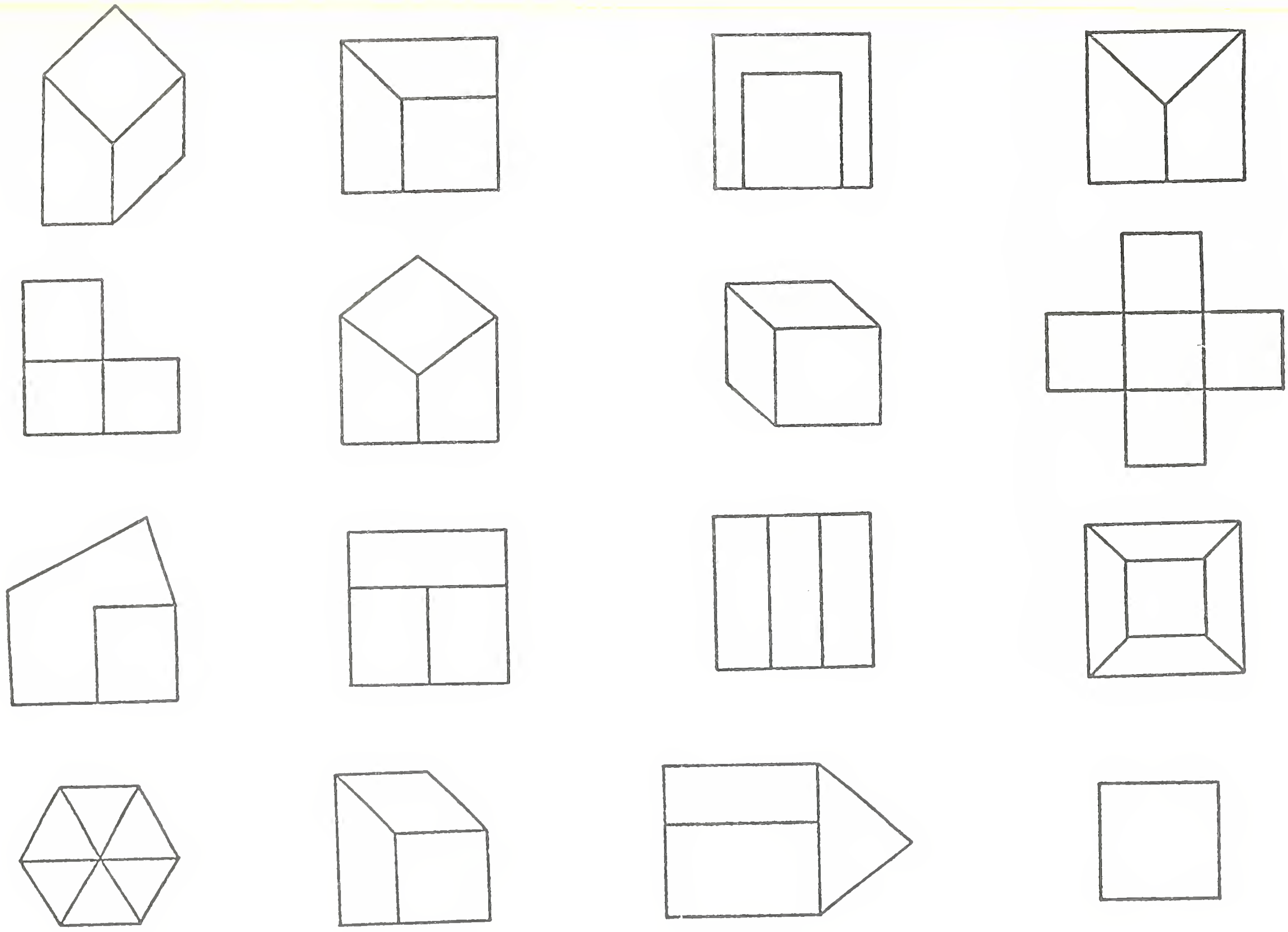
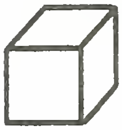


Fig. 5.--Pictures for the cube matching task

A. An oblique projection



B. The isometric projection

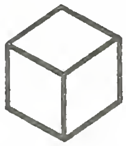
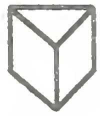


Fig. 6.--Line drawings of the cube

A. Triangular solid (prism)



B. Tetrahedron

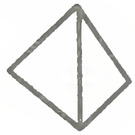


Fig. 7.--Perspectival representations of other solids

a hexagon) in order to make the cube less salient. Whether a child (a) selected the conventional perspectival line drawing as the best picture of the cube, (b) chose the solid cube in response to each of the projective drawings of the cube, and (c) chose the flat wooden square in response to the line drawing of a square were taken as indices that he associated the solid object with the appropriate two-dimensional representation.

2. Cube Drawing

Each child drew a picture of a solid wooden cube. He also copied drawings of the oblique projection of a cube and of the isometric projection of a cube. The solid cube to be drawn was set on the table in front of the child so oriented that three surfaces were visible, and he was encouraged to draw it as it was without moving it or picking it up (see Figure 8). The figural stimuli, drawn with heavy black lines on four- by six-inch index cards, were placed above the child's five- by seven-inch drawing tablet, in which he sequentially copied the figures.

All of the cube drawings were classified both according to the child's grade in school and according to which stimulus (solid cube, oblique projection, isometric projection) was drawn. These drawings were compared by grades to see if the predicted developmental sequence of forms was present.

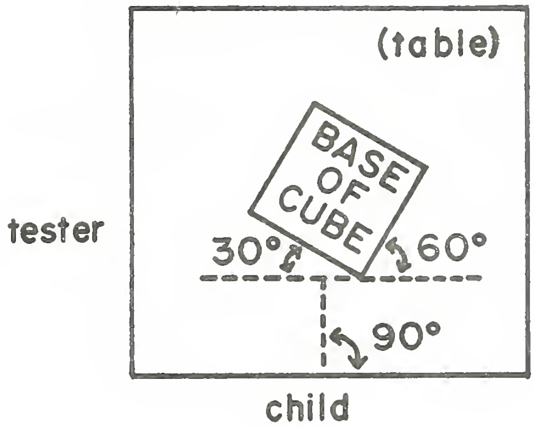


Fig. 8.--Solid cube presentation

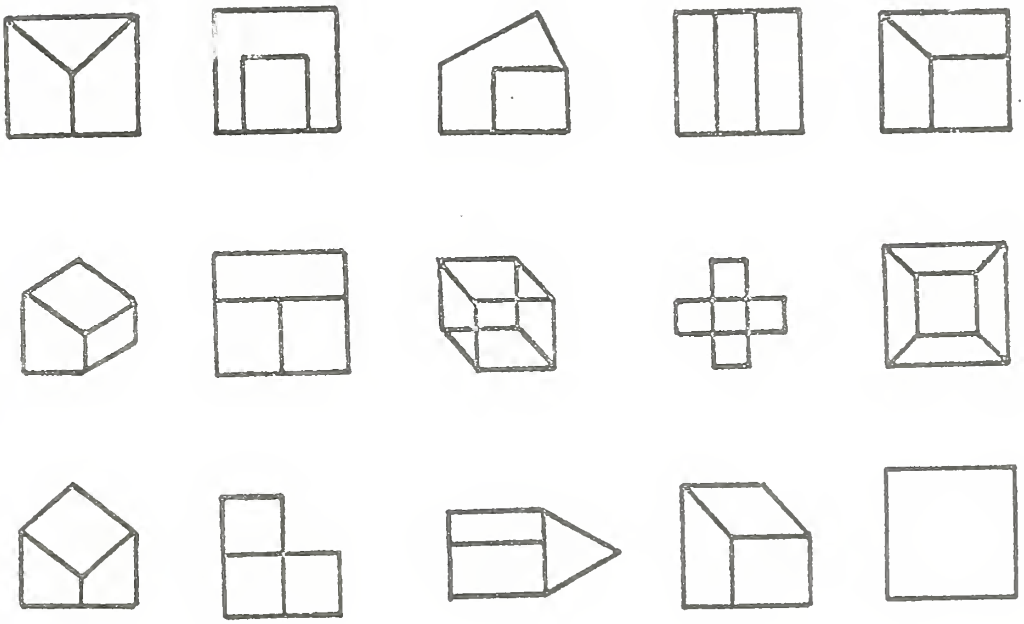


Fig. 9.--Children's Cubes Scale items, in order of presentation

3. Children's Cubes Scale

The above procedures establish an age-related sequence of forms drawn with the cube as stimulus. Additional evidence indicative of the sequence of development which the cube drawings represent was obtained by seeing whether children were able to copy forms which are characteristic of how children less advanced than themselves draw a cube, when they could not accurately copy forms characteristic of how children more advanced than themselves draw a cube. For this test, a set of fifteen drawings (see Figure 9) was selected from pilot data as representative of children's attempts to draw a cube. The children in the present study copied each of these designs, called the Children's Cubes Scale, and based on the average accuracy with which they copied each design, the designs were scaled for difficulty.

Thereafter, the age-related sequence established from children's drawings of the solid cube was compared to the sequence resulting from arranging the Children's Cubes in order of difficulty.

4. Graphic Elements

Data pertaining to the second experimental issue, the development of children's competence with graphic elements, were obtained by having children (a) copy ten angles, ranging from 15° to 150° at fifteen-degree intervals; (b) for each of the ten angles, select an angle of the same size from a page with all ten angles drawn on it in random arrangement (see Figure 10); and (c) copy pairs of horizontal, vertical, and diagonal parallel lines.

Scores for the angle tasks were calculated as follows: (a) for angle copying, (1) the absolute difference between the size of the stimulus angle and the size of the angle drawn, and (2) the amount of change in line direction in the child's drawing; (b) for angle matching, the absolute difference between the size of the stimulus angle and the size of the angle selected.

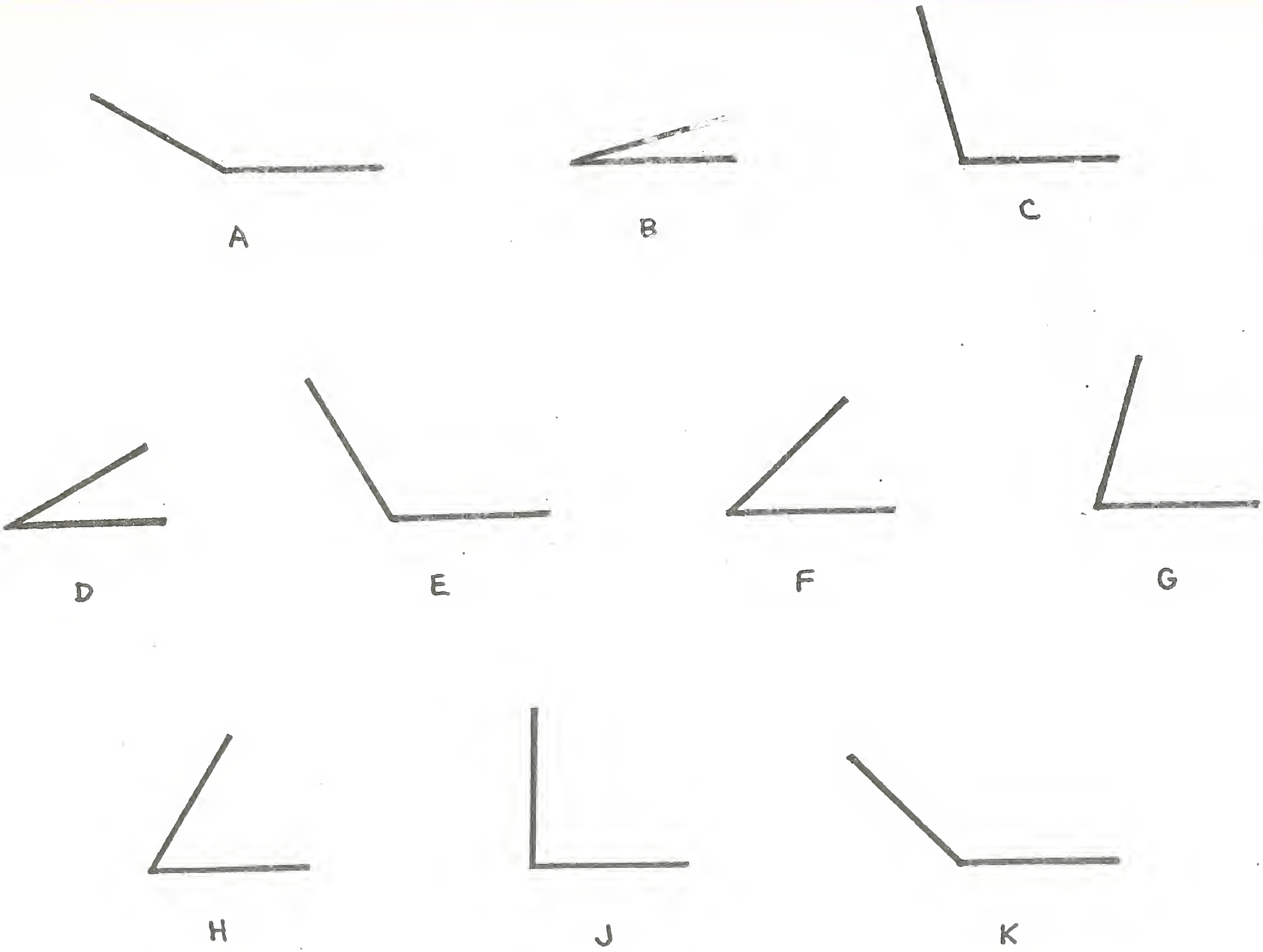


Fig. 10.--Pictures for the angle matching task

These scores were analyzed according to the size of the stimulus angle and according to grade, in order to determine (a) whether accuracy on the tasks is related to age, (b) whether some angles are more difficult than others, and (c) whether the pattern of accuracy is the same for angle drawing as for angle discrimination.

Scores for the parallel lines task were derived from (a) how accurately the lines were oriented on the page with respect to horizontal, vertical, and diagonal; and (b) how much the pair of lines deviated from parallel. The scores were analyzed according to the direction of the lines and according to grade, with the results indicating (a) whether competence at drawing parallel lines is age-related, and (b) whether it is more difficult to draw parallel lines in one direction than in another.

From these analyses, developmental sequences were abstracted for angle copying and for drawing parallel lines. These sequences were then compared to the cube drawing sequence from Experiment 1, to learn if children master the drawing of isolated graphic elements in the same sequence as they master integration of these elements into their cube drawings.

5. Mock-Cube

The third experimental question, how does acquisition of strategies for combining the specific perceptual-motor skills contribute to the ability to draw the object, was studied by use of the mock-cube. As described above, the mock-cube is a flat wooden hexagon, with lines painted from alternate corners to the center. Drawing the mock-cube yields a line drawing of a cube, although the stimulus object bears little resemblance to the wooden cube. Children's drawings of mock-cubes were compared with their cube drawings and with their copies of line drawings of the cube to determine whether a planar projection of a cube was more readily achieved through

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drawing the mock-cube than through drawing any of the three cube stimuli.

D. Scoring

A standard procedure was adopted for use in measuring the angles which were drawn. For each line drawn by a child, the best straight line was found (see Figure 11A). The criterion used for the best line was that the best line (b) should be drawn such that it created on either side of itself, between it and the child's line (c), an equal area (d and e). In cases where the child's line was shaped like a single curve, it was assumed that only the portion of the line surrounding area d had been drawn, and that if the line were continued then area e could be found. A score reflecting the size of the angle drawn by the child was then determined by measuring the angle between the two best lines (see Figure 11B). A second score was determined as follows: The maximum angular separation between the two sides of the angle was measured, and the minimum angular separation between the two sides of the angle (see Figure 11C). The difference between these two numbers was used as an index of the line variation for the drawing. In addition to being scored for angle size and for extent of line variation, angles were classified for the presence of any of a number of particular drawing errors. These aberrations are illustrated in Figure 12.

Two measurements were obtained for each pair of parallel lines. The best line was determined for each of the two lines, and the angle between these two lines was taken as a measure of the discrepancy from parallel (see Figure 11D). Secondly, the angle was measured between the bottom edge of the paper and each of the best lines. The smaller of these two angles was used as an index of orientation on the page.

For scoring Children's Cubes Scale items as right or wrong and for scoring the stage of cube drawings, the same method for taking the "best"

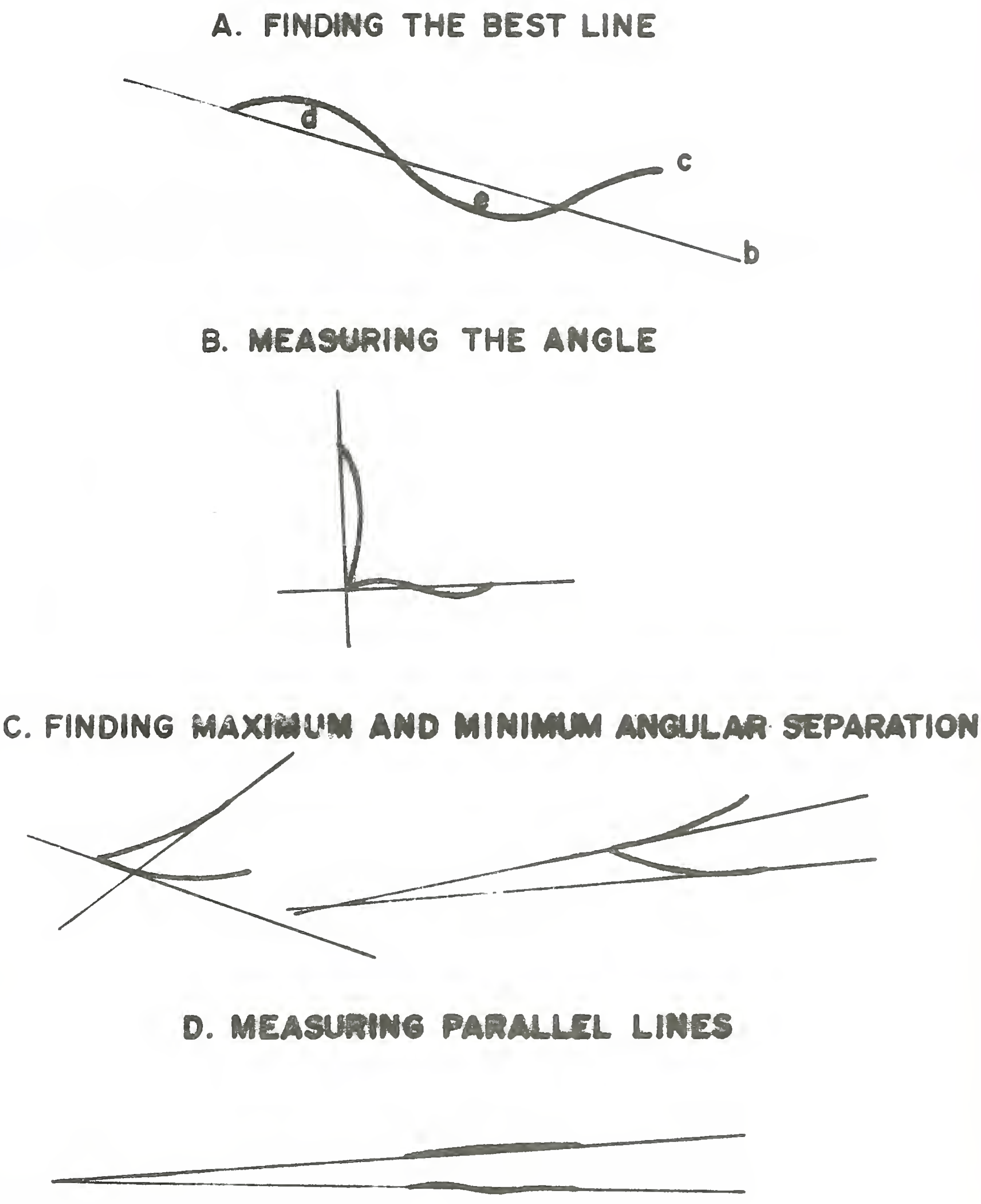

Fig. 11.--Scoring techniques for graphic elements

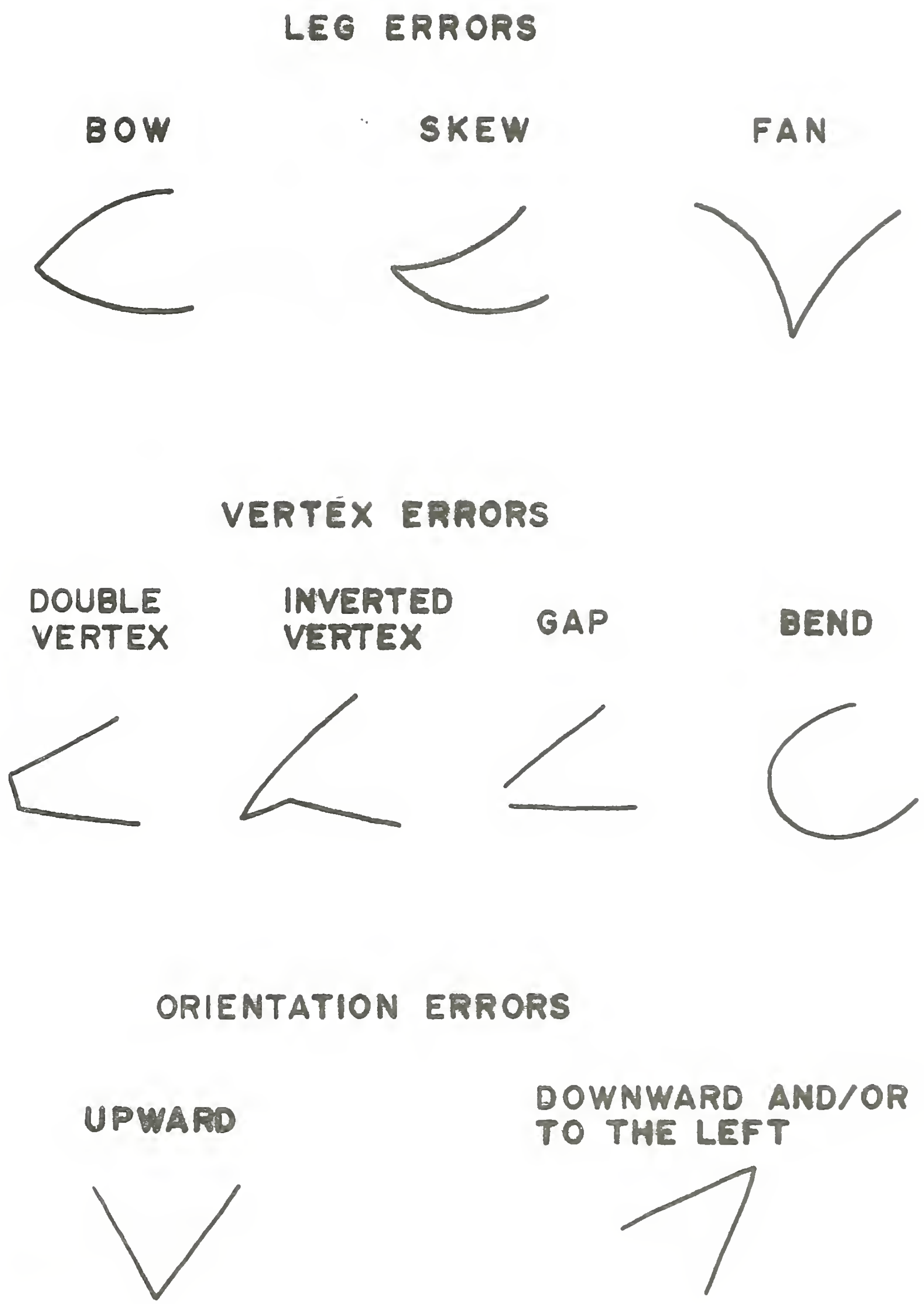

Fig. 12.--Angle copying aberrations

straight line was used in measuring the angle between parallel lines. The following criteria (illustrated in Figure 13) were adopted for determining whether a Children's Cubes Scale drawing was scored as correct.

1. Score wrong if a straight line is substituted for an angle or in a three-line intersection.
2. Score wrong if lines which were parallel in the stimulus drawing are copied with an angular separation equal to or exceeding 15^{o}.
3. Score wrong if a straight line is drawn with an angular shift of 15^{o} or more at some place along it.
4. Score wrong if three lines meant to intersect at a single point are drawn such that their terminus is one-eighth of an inch or more away from that point.
5. Score wrong if the number of constituent polygons is wrong.
6. Do not score wrong if the only errors are disproportions or rotations, while the correct relationships are preserved.

The same criteria pertaining to parallel lines and intersections were applied to scoring the stages of cube drawings. The following stages were differentiated (illustrated in Figure 4):

1. a quadrilateral
2. a design composed of quadrilaterals
    a. with a square outline
    b. not with a square outline
3. a design which contains some diagonal lines, that is, has lines drawn in three directions
    a. with a square outline
    b. not with a square outline
4. a design which has lines parallel to each other in three different directions

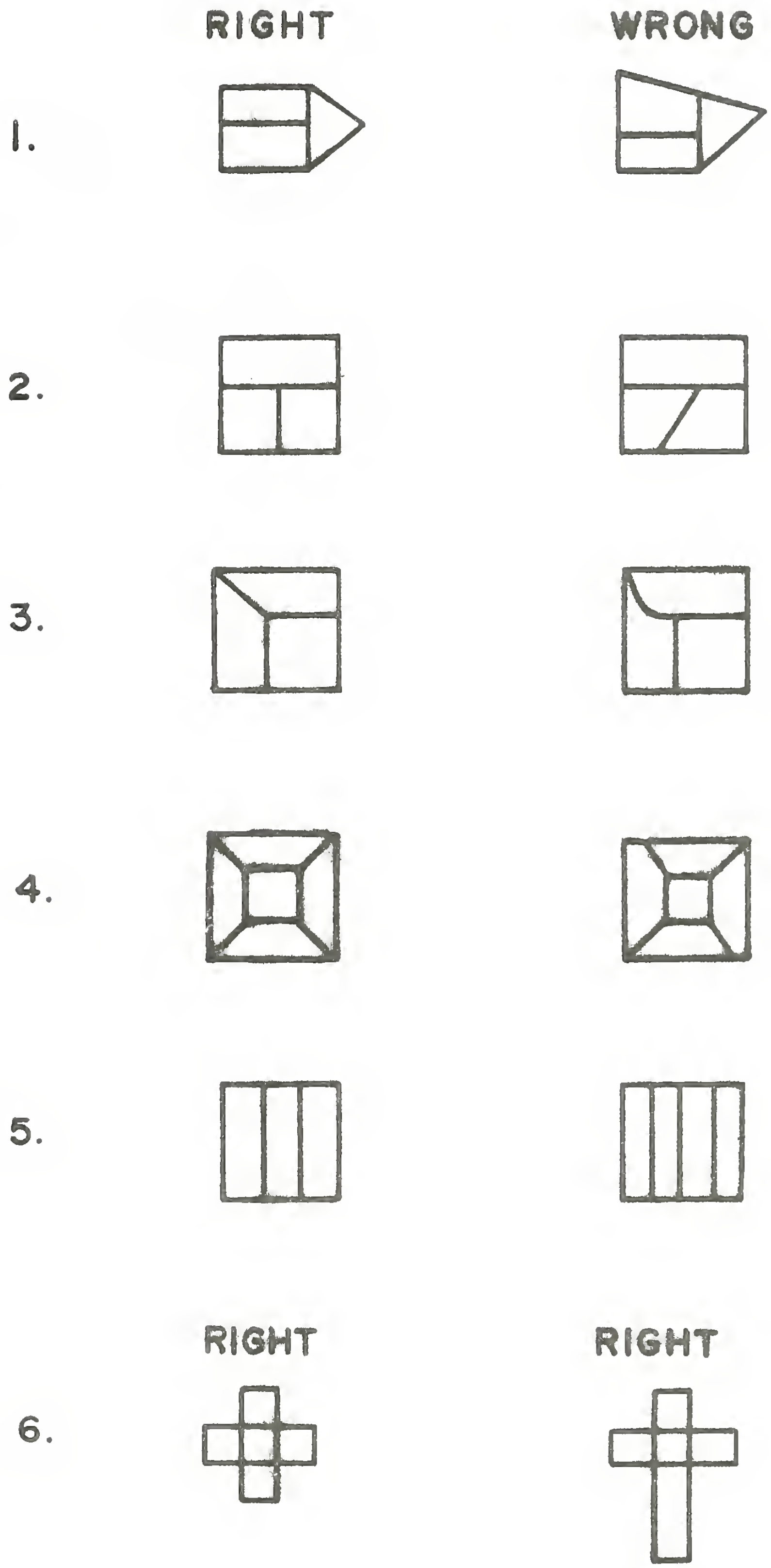

Fig. 13.--Children's Cubes Scale scoring criteria

a. a transparent cube (including the Necker cube)

b. a picture of a solid

5. an oblique or isometric projection of a cube, which designs both contain three lines parallel to each other in three different directions.

IV. RESULTS

A. Pearson School

1. Experiment 1

Drawings of the solid cube, copies of the oblique projection of the cube, and copies of the isometric projection of the cube made by all of the subjects were inspected to determine whether the forms of cubes drawn by children in the different grades fit the hypothesized developmental sequence. Using the scoring criteria described in part D above, each drawing was rated according to which stage it represented. One rater made his ratings with knowledge of neither the age of the child who drew the cube nor the particular cube stimulus which was being drawn or copied. The two independent raters agreed on 96 per cent of the stage scores assigned, and 94 per cent of the sub-stage scores. To illustrate this relationship between frequency of usage of each of the hypothesized stages and the children's grade in school, frequency profiles for each of the three cube stimuli are presented in Figure 14.[1] The graph for each of the stages shows the frequency with which that stage was used by children of each grade. As can be seen, the lower stage forms are drawn more often by children in the lower grades, and the higher stage forms appear more frequently in drawings by children in the higher grades. There was one exception: for all three stimuli, the third grade class appears to be developmentally higher than the fourth grade class.

Calculation of a Kendall's tau coefficient for each of these

[1]Contingency tables corresponding to Figures 14 and 15 are in Appendix B, Tables I through III.

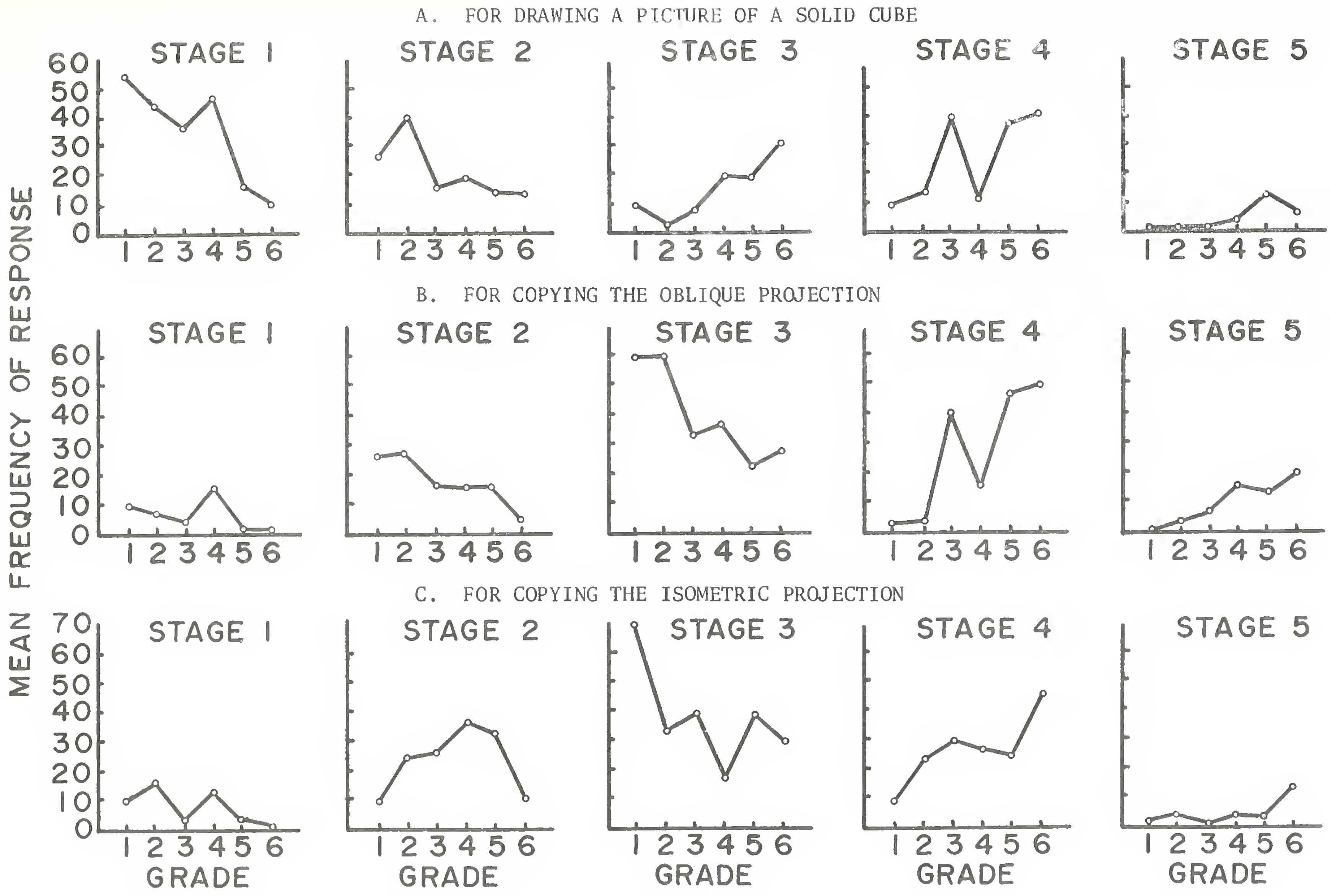

Fig. 14.--Mean frequency of the five developmental stages of cube drawing, across age groups

distributions of stage scores indicates whether the subjects are placed in the same order when they are classified by the stage of their cube drawing as when they are classified by their grade in school. The values of this statistic were .306, .344, and .171 for the solid cube, the oblique projection, and the isometric projection respectively. With 183 subjects, these values are significant at $p<.001$.

Separate profiles for each grade, showing the relative frequency of drawings of each stage within each grade, are presented in Figure 15. From the shape of the graph for the stages of drawing the solid cube, it can be seen that a greater gain is made between fourth and fifth grades than between any other two grades. For copying the oblique projection, the greatest gain is between grades two and three. It is further apparent that, for drawing the solid cube and for copying the oblique projection, the higher average stage of the third graders compared to the fourth graders results from their having produced a large number of stage 4 drawings, while the fourth graders produced a disproportionately large number of stage 1 drawings. For copying the isometric projection, the difference between third and fourth grade appears to be due to the fourth graders having drawn a large number of stage 2 responses relative to their number of stage 3 responses.

Except for the reversals and anomalies which have been pointed out, patterns of stage usage show a continuous shift from lower to higher stages from grade one through six. These results confirm hypothesis 1, that there are standard age-related stages for drawing a picture of a solid cube; hypothesis 2, that there are standard age-related stages for copying the oblique projection of the cube; and hypothesis 3, that the same sequence of hypothesized stages occurs for both tasks.

The extent to which a child's performance on one cube drawing task

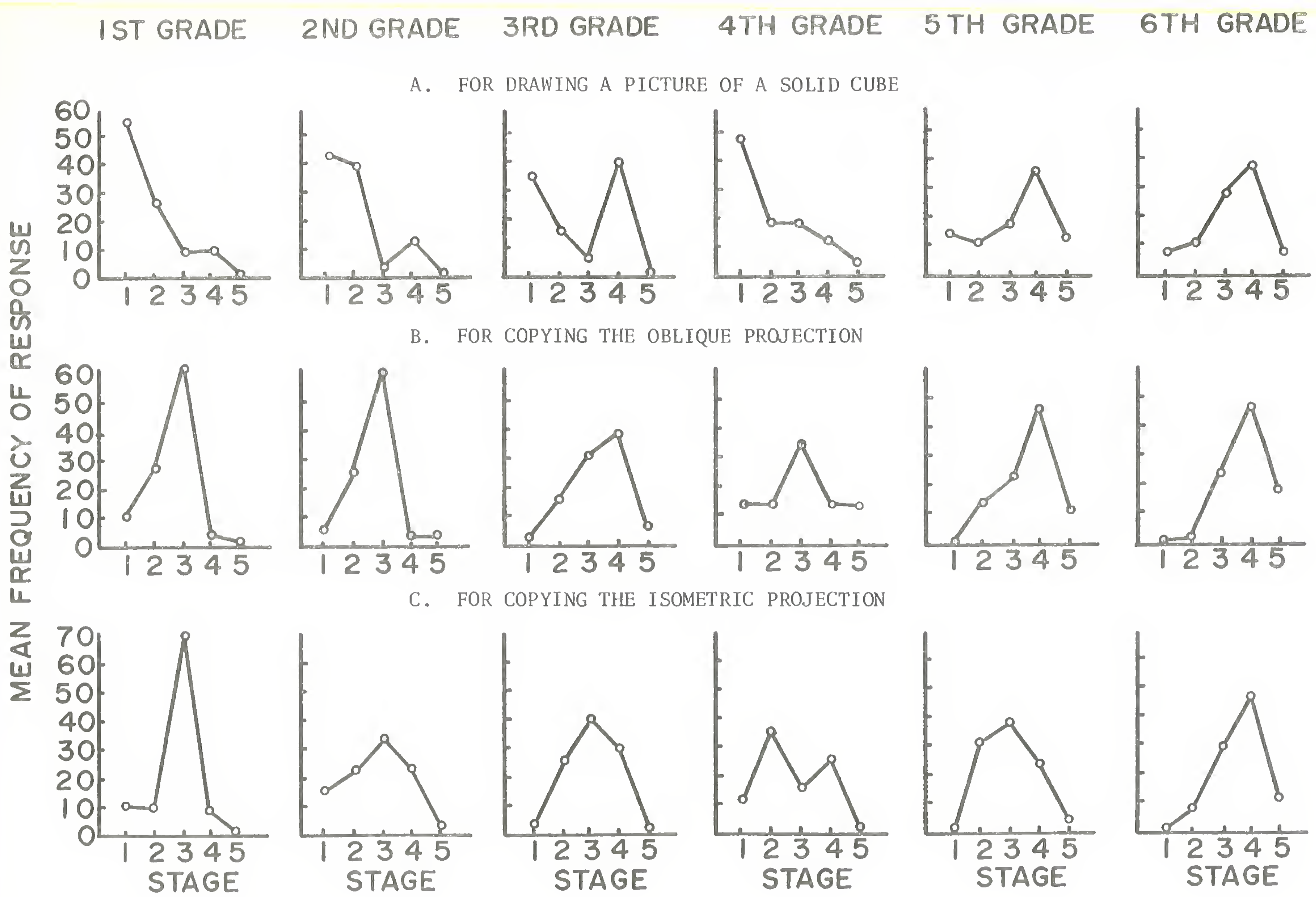

Fig. 15.--Mean frequency of the cube drawing stages within each grade

can be predicted from his performance on another is indicated by intercorrelations of children's stage scores for the three different tasks, found in Appendix B.[1] These correlations suggest that a child's relative competence on one of these tasks gives a rather good indication of his relative competence on the others. On the whole, children drew the solid cube at a lower stage than they copied either projection of the cube. The average difference between the stage of copying the oblique projection and the stage of copying the isometric projection remained fairly constant across grades, while the average difference between the stage of children's drawings of the solid cube and their copies of either of the two-dimensional projections decreased slightly in the higher grades.

At the time when the stages were hypothesized, substages were proposed for stages 2 through 4, as illustrated in Figure 4. In Figure 16 the criteria for each substage are reviewed and more examples are given. If the substages were found to follow in order, they would elaborate and support the hypothesized developmental sequence.

The following observations focus on whether classification of children's drawings by substage leads to a clearer developmental sequence than classification by stage alone. Tables of frequency scores which result from classification by substage are presented in Table 3. In the cases of the solid cube and the oblique projection, substages 2a and 2b do not occur in progression. In the case of the isometric projection, substage 2a appears at

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[1]The hypothesized stages of children's cube drawing constitute measurement at an ordinal level, with no particular reason to assume equal intervals between any two stages. For this reason, the use of parametric statistical techniques is not fully justified, and results must be interpreted with caution. Therefore, I regard these statistics as descriptive, and will be more interested in the general pattern of the results than in precise significance levels. Other sets of data which are analyzed in this study meet the requirements of ratio measurement. Carefully interpreted parametric techniques can best indicate interrelationships among all of these variables.

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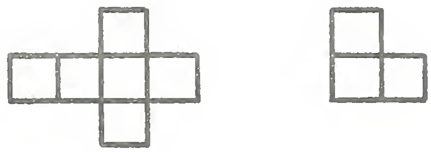
STAGE 2--drawings constructed only of horizontal and vertical lines

SUBSTAGE A--square outline

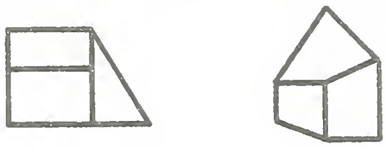
SUBSTAGE B--outline has more than four sides



STAGE 3--drawings constructed of horizontal, vertical, and diagonal lines

SUBSTAGE A--square outline

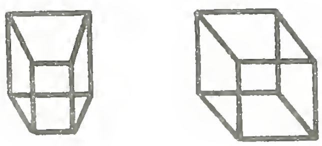
SUBSTAGE B--outline not square



STAGE 4--drawings which contain parallel diagonal lines

SUBSTAGE A--drawings with a square outline;

and other transparent cubes, based upon superimposed squares



SUBSTAGE B--outline has more than four sides, and there is no effort to show any hidden lines

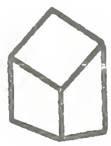


Fig. 16.--Description of substages for stages 2, 3, and 4

a younger age than substage 2b. Complicating the picture is the fact that, for the isometric projection, substage 3a appears at a younger age than either of the stage 2 responses. Within stage 3, juxtaposed (3b) drawings are slightly more common than 3a drawings in response to the task of drawing a picture of a solid cube, while squares subdivided with diagonals (3a) are more

TABLE 3

SUBSTAGES OF CUBE DRAWING, PEARSON SCHOOL

	Substages							
Grade	1	2a	2b	3a	3b	4a	4b	5
			A. Drawing a solid cube					
1 (N = 30)	.53	.20	.07	.00	.10	.03	.07	.00
2 (N = 30)	.43	.30	.10	.00	.03	.10	.03	.00
3 (N = 30)	.37	.10	.07	.00	.07	.33	.07	.00
4 (N = 32)	.47	.16	.03	.16	.03	.09	.03	.03
5 (N = 31)	.16	.06	.06	.03	.16	.16	.23	.13
6 (N = 30)	.10	.13	.00	.03	.27	.27	.13	.07
Total	.34	.16	.06	.04	.11	.16	.09	.04
			B. Copying the oblique projection of the cube					
1 (N = 30)	.10	.27	.00	.43	.17	.00	.03	.00
2 (N = 30)	.07	.23	.03	.50	.10	.00	.03	.03
3 (N = 30)	.03	.07	.10	.17	.17	.10	.30	.07
4 (N = 32)	.16	.12	.03	.12	.25	.06	.09	.16
5 (N = 31)	.00	.13	.03	.10	.13	.10	.39	.13
6 (N = 30)	.00	.00	.03	.07	.20	.20	.30	.20
Total	.06	.14	.04	.23	.17	.08	.19	.10

TABLE 3--Continued

Grade	Substages 1	2a	2b	3a	3b	4a	4b	5
C. Copying the isometric projection of the cube								
1 (N = 30)	.10	.07	.03	.33	.37	.00	.10	.00
2 (N = 30)	.17	.17	.07	.27	.07	.03	.20	.03
3 (N = 30)	.03	.20	.07	.23	.17	.13	.17	.00
4 (N = 32)	.12	.22	.16	.06	.12	.06	.22	.03
5 (N = 31)	.00	.19	.13	.10	.29	.06	.19	.03
6 (N = 30)	.00	.10	.00	.03	.27	.10	.37	.13
Total	.07	.16	.08	.17	.21	.07	.21	.04

commonly drawn when a child is asked to copy a projection of a cube. Overall, substages 3a and 3b do seem to follow in ordinal sequence. The same is true for the substages of 4. Within stage 4, transparent cube drawings (4a) appear at a relatively young age. In particular, one-third of the third graders drew a 4a picture to represent the solid cube. For substage 4b and stage 5, the preponderance of drawings of the solid cube were from an isometric rather than an oblique perspective.

To see whether substage classification helped to predict overall cube drawing stage, children's substage scores were correlated with their grades. The correlations were of approximately the same magnitude as the correlations between stage and grade.[1] These results suggest that substage classification, while helping in the description of the developmental sequence, contributes minimally to prediction.

The preceding analysis has centered on a single independent variable, children's grade in school. Other variables which might be related to the stage at which a child draws a cube include: the order of presentation of the three cube stimuli, the child's sex, and his IQ.

The major question about order of presentation pertains to the solid cube. Is the cube drawn differently when it is the first drawing task from how it is drawn when it is presented after the child has already copied one or both projections of the cube? The results of a two-way analysis of variance[2] indicate a significant grade effect, and a significant Grade x Order interaction, but no significant main effect due to order of presentation. Examination of the mean scores for each grade and presentation sequence shows that

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[1]Tables of correlations between tasks are in Appendix B, Tables VI and VII.

[2]All analyses of variance having to do with cube stages are summarized in Appendix C.

third and fifth grade students drew cubes at a higher stage if they had previously copied the two-dimensional projections. Third graders who received the solid cube for their first drawing task did more poorly than either first or second graders under the same condition.

Similar analyses were performed for oblique and isometric data, to determine whether the drawings were copied better in any particular order of presentation. In both of these cases, the main effect due to grade was significant, but neither order nor Grade x Order was significant.

The cube drawings were examined for sex differences by separately plotting, for the boys and the girls, the mean stage scores for each cube stimulus in each grade (see Figure 17). It is apparent that, with a few exceptions, the average stage of the boys's drawings in each grade tends to be higher than the average stage of the girls's. The stage scores for each cube stimulus were analyzed with respect to grade and sex effects. The results for drawing a picture of a solid cube indicate significant effects for both grade and sex, but no significant interaction. For the tasks of copying the oblique and isometric projections, analysis of variance of the stage scores indicates a significant age effect, but no main effect or interaction due to sex.

Cube drawing stages and children's competence on verbal IQ tests were generally uncorrelated. The role played by IQ was further assessed by repeating the analysis of variance using grade and sex as independent variables, this time with the effects removed which were due to the covariance of IQ and cube drawing stage. The regression of IQ on stage of drawing the solid cube and on stage of copying the isometric projection were both non-significant. The regression of IQ on stage of copying the oblique projection was significant. The significance of the grade effect, however,

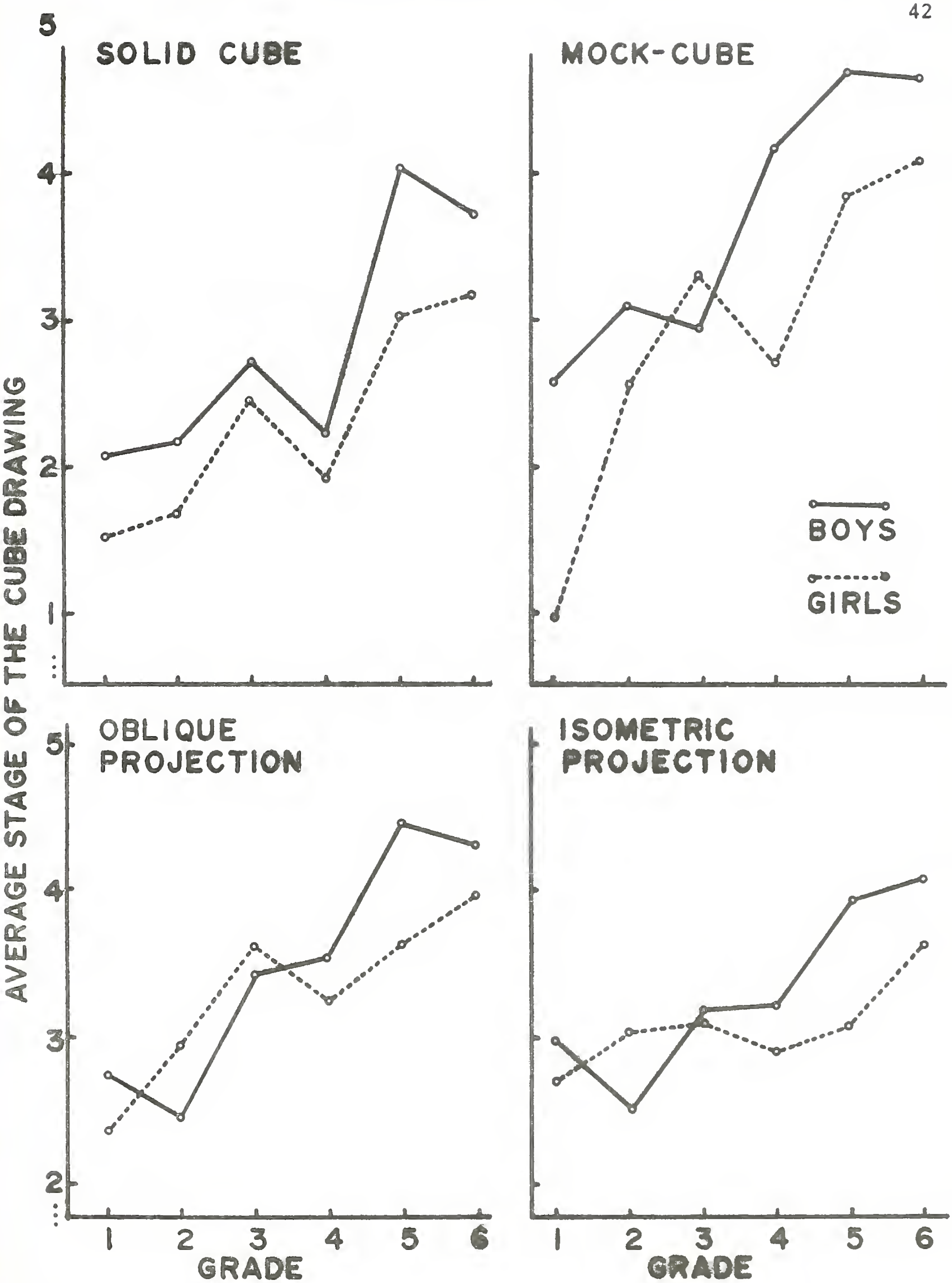

Fig. 17.--Sex differences in the average stage at which children in each grade draw each of the cube stimuli, Pearson School

was not appreciably decreased, which suggests that a child's grade does account for most of the variance.

In summary, these analyses of the cube stage data have shown that stage of drawing a solid cube is related to the sex of the child and is affected by the order of presentation of a set of cube tasks, whereas verbal IQ is associated with accuracy of copying the conventional perspectival representation of a cube.

Correctly associating the solid cube with its two-dimensional line drawing did prove to be far easier than the task of drawing a cube, as is shown by the frequencies in Table 4. On the first matching task, selecting which is the best line drawing of a solid cube, 37 per cent of first graders chose the oblique projection of the cube. Another 20 per cent chose the square as best and the oblique projection as the next best choice. By sixth grade, 70 per cent of the children immediately associated the line drawing with the solid, while a total of nearly 90 per cent said that either the oblique projection or a square was the best way to draw a cube. No other single match accounts for more than 20 per cent of the choices.

In the other matching task, the child was shown a line drawing and asked to select which one of eight wooden blocks the picture portrayed. Table 5 shows which blocks were selected for the oblique projection of the cube, the isometric projection of the cube, and a line drawing of a square. In both matching tasks the same number of children matched the solid cube with the oblique projection. On the average, the same number of children also saw the isometric projection of the cube as picturing the solid cube, but with less change in performance from one grade to another. Finally, only 24 per cent of the first graders and 7 per cent of the sixth grade children said that the solid cube was the block which was pictured by the line drawing of a

TABLE 4

CUBE MATCHING FREQUENCIES[a]
(Picture Selected as the Best Picture of the Solid Cube)

Grade	First Choice: Oblique Projection	First Choice: Square	Second Choice, When First Choice was Square: Oblique Projection	Second Choice, When First Choice was Square: Other	First Choice: Other
1	.37	.33	(.20)	(.13)	.30
2	.67	.13	(.06)	(.07)	.20
3	.63	.27	(.20)	(.07)	.10
4	.66	.22	(.22)	(.00)	.12
5	.65	.32	(.25)	(.07)	.03
6	.70	.23	(.17)	(.06)	.07

TABLE 5

BLOCK MATCHING FREQUENCIES[a]

A. Block selected when presented the oblique projection to match					B. Block selected when presented the isometric projection to match				
Grade	Cube	Mock-Cube	Square	Other	Grade	Cube	Mock-Cube	Square	Other
1	.57	.03	.13	.27	1	.63	.07	.17	.13
2	.70	.07	.03	.20	2	.84	.10	.03	.03
3	.83	.03	.07	.07	3	.67	.13	.07	.13
4	.78	.03	.13	.06	4	.74	.20	.03	.03
5	.87	.07	.03	.03	5	.84	.10	.00	.06
6	.94	.03	.00	.03	6	.84	.13	.00	.03

C. Block selected when presented the line drawing of a square to match

Grade	Cube	Mock-Cube	Square	Other
1	.24	.00	.73	.03
2	.23	.00	.77	.00
3	.07	.00	.90	.03
4	.31	.00	.69	.00
5	.13	.00	.87	.00
6	.07	.00	.93	.00

[a]Frequencies expressed in percentages.

square. These numbers are remarkably small when contrasted with the 52 per cent of first graders and 10 per cent of sixth graders who drew a square when asked to draw a picture of a solid cube.

A child's performance on these matching tasks and his cube drawing stage were generally uncorrelated. Girls tended to score slightly lower on cube matching than boys, but neither the sex effect nor the Grade x Sex interaction was significant.[1] Cube matching was also uncorrelated with IQ.

What is demonstrated by the cube matching results is that by first or second grade most children have acquired the association between a solid cube and a perspectival drawing of a cube, and that this knowledge ceases to be decisive in their being able to draw a cube.

The Children's Cubes Scale data bear on the question of whether children can copy forms from stages lower than their own cube drawing stage but cannot copy higher stage cube forms. Before this question can be answered directly, it must be established (a) that the order of difficulty of the Children's Cubes Scale forms is the same for all subjects, and (b) that the order of difficulty of copying the Children's Cubes Scale forms corresponds directly to the developmental sequence of forms observed for the task of drawing a picture of a solid cube. If both these conditions are met, then performance on this scale may be usefully compared to the cube drawing stages.

Each of the Children's Cubes Scale designs copied by each of the subjects was scored right or wrong according to the criteria set out in the procedural section. Inter-rater agreement was 97 per cent. Scores for each design are presented in Table 6. It appears that the same sequence of designs describes their order of difficulty for children at any age, and that older children can copy more difficult designs as well as the easier ones which the

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[1]See Appendix C, Table IV.

TABLE 6

AVERAGE SCORE WITHIN EACH GRADE FOR THE CHILDREN'S CUBES SCALE FIGURES[a]

		Grade						Average Score for the Design
		1	2	3	4	5	6	
	Av	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Av	1.467	1.233	1.100	1.062	1.032	1.033	1.153
	Av	1.367	1.333	1.233	1.125	1.0	1.033	1.180
	Av	1.600	1.233	1.067	1.094	1.064	1.100	1.191
	Av	1.533	1.467	1.100	1.062	1.032	1.067	1.208
	Av	1.700	1.533	1.133	1.219	1.064	1.100	1.290
	Av	1.600	1.467	1.200	1.281	1.161	1.133	1.306
	Av	1.733	1.600	1.367	1.250	1.161	1.033	1.355
	Av	1.667	1.533	1.367	1.344	1.161	1.133	1.366
	Av	1.867	1.900	1.733	1.531	1.322	1.300	1.606
	Av	1.900	1.900	1.733	1.500	1.452	1.467	1.656
	Av	1.867	1.867	1.733	1.719	1.452	1.400	1.672
	Av	1.967	1.867	1.800	1.750	1.710	1.700	1.798
	Av	2.0	2.0	1.733	1.812	1.613	1.667	1.803
	Av	2.0	2.0	1.867	1.875	1.871	1.800	1.902
Average Score for the Grade		1.684	1.596	1.411	1.375	1.273	1.264	1.432

[a]The range of the scores is from +1.000 to +2.000, with a score of 1 indicating that the designs were drawn correctly, and a score of 2 indicating that the designs were drawn incorrectly.

younger children can copy.

A way to establish the sequence of difficulty of the Children's Cubes figures is to see if they qualify as a Guttman scale.[1] The scores on the Children's Cubes Scale do form a Guttman scale with a reproducibility of .88. The designs are depicted in order of difficulty in Table 6.

The designs in the Children's Cubes Scale were also scored according to the stage of cube drawing which each of them would be considered to represent. Then, the stage scores and the Guttman scale scores were compared by rank-order correlation in order to see whether the two sequences were the same. The Spearman rank-order correlation coefficient which resulted from this procedure was .92, further supporting the proposed developmental sequence of forms.

Because the Children's Cubes Scale can be regarded as a Guttman scale, the total number of correct drawings was taken as a single score for a child on the Children's Cubes Scale. There were no significant differences between the boys and girls on their Children's Cubes Scale scores.[2] This score correlated .44, .54, and .44, respectively, with the stage at which the child drew a picture of a solid cube, copied the oblique projection, and copied the isometric projection of the cube.

The correlation coefficient between the Children's Cubes Scale scores and the stage scores from the cubes which they drew reveals little information about the relative magnitude of the two sets of scores. Therefore, the average

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[1]A set of items are said to form a Guttman scale when they can be put into an order such that the following condition is met. An individual's getting a particular item correct implies that he also got all lower-ranked, that is, easier, items correct. The BMD05S program, written by the Health Sciences Computing Facility of the University of California in Los Angeles, scales items according to this criterion, and computes a coefficient of reproducibility to indicate the extent to which the assumptions underlying a Guttman scale have been met by the data.

[2]See Appendix C, Table V.

TABLE 7

AVERAGE CHILDREN'S CUBES SCALE SCORE ACROSS ALL GRADES
FOR CHILDREN WHO DREW CUBES AT EACH STAGE

	Stage of Cube Drawing				
Cube Stimulus	1	2	3	4	5
Solid cube	7.111	7.462	9.000	10.255	13.429
Oblique projection	5.455	6.594	7.712	10.531	11.556
Isometric projection	5.077	7.744	7.986	10.260	12.429

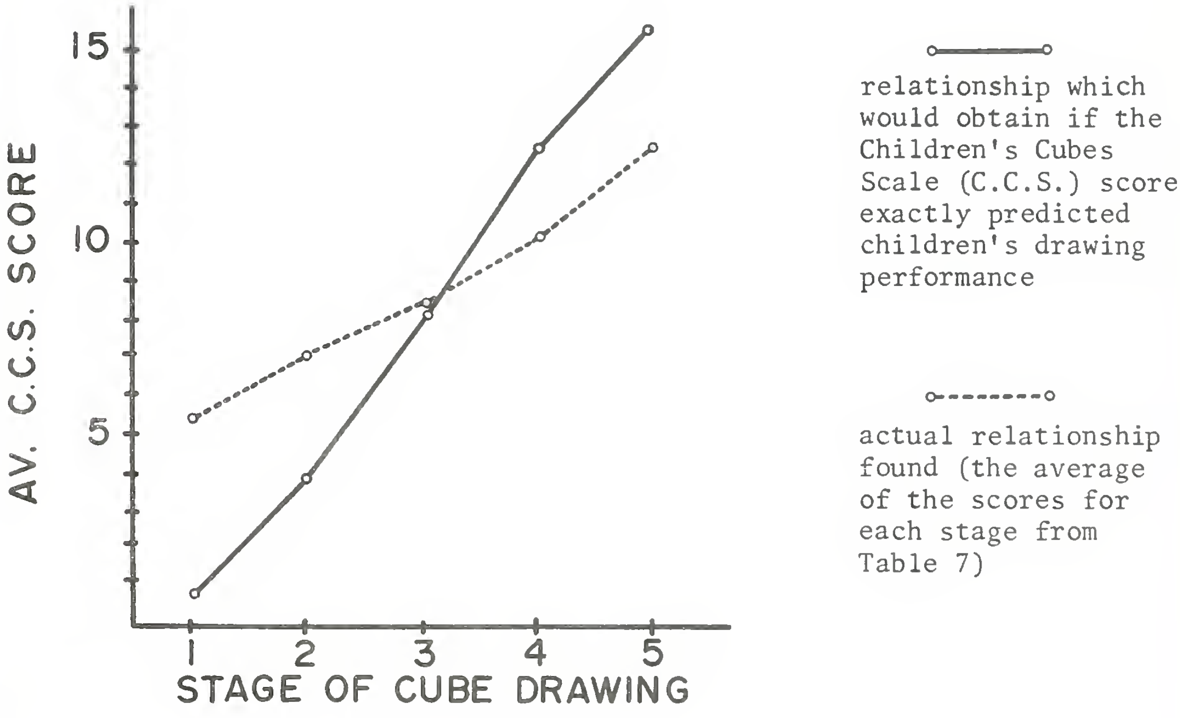

Fig. 18.--Correspondence between Children's Cubes Scale score and stage of cube drawing

Children's Cubes Scale score was separately examined for children who spontaneously drew cubes at each stage in response to the request to draw a picture of the solid cube. These data, shown in Table 7, indicate what relationship there is between the levels of drawing cubes to request and copying forms. If these were perfectly related, then the stage to which each child's Children's Cubes Scale score corresponds would be the same as the stage at which he drew the cube. This hypothetical relationship and the actual relationship found are plotted in Figure 18. It can be seen that at lower stages of cube drawing children can copy forms equivalent to stages higher than those which they spontaneously draw. Children at the higher stages of cube drawing frequently do not correctly copy all of the Children's Cubes Scale figures which correspond to their stage. For children in the middle stages of cube drawing, the Children's Cubes Scale score corresponds quite well with drawing stage. In sum, the Children's Cubes Scale represents a greater possible range of performance than does the cube drawing task.

2. Experiment 2

The sizes of the angles copied by each subject were measured with a transparent protractor with a rotating indicator, which device permitted test-retest and inter-rater accuracy to one degree.

The data for angle copying, presented in Table 8, include: the average size of angle drawn by the children (measured using the geometrically best straight line), the standard deviation for angle size; the average amount of line variation in the drawing of the angle (measured by taking the difference between the maximum and minimum angular separation), the standard deviation for line variabion. Each subject drew all ten of the angles, and it is reasonable to assume that the kinds of errors the child made in copying one angle were not independent of the kinds of errors he made in copying other

TABLE 8

ANGLE COPYING DATA

A. Mean Scores

Angle		Grade 1	2	3	4	5	6	Average
15°	av. size of angle drawn	26.47	32.33	26.13	23.69	25.19	22.63	26.04
	s.d. of angle size	9.81	13.06	8.93	9.29	9.45	6.88	10.09
	av. amount of line variation	28.93	18.23	16.03	16.41	13.06	15.27	17.95
	s.d. of line variation	12.33	9.65	10.03	12.88	9.96	9.99	11.91
30°	av. size of angle drawn	32.30	42.37	35.00	33.88	34.87	34.80	35.51
	s.d. of angle size	11.77	16.75	12.70	9.21	9.32	7.81	11.88
	av. amount of line variation	33.33	16.13	15.93	18.56	10.03	14.40	18.03
	s.d. of line variation	18.80	14.57	8.91	10.53	7.99	11.32	14.34
45°	av. size of angle drawn	36.37	42.73	39.23	39.19	44.84	42.37	40.79
	s.d. of angle size	16.68	15.39	13.73	11.79	7.46	11.34	13.17
	av. amount of line variation	32.90	17.97	13.73	13.03	11.94	17.20	17.71
	s.d. of line variation	24.78	13.71	8.26	8.80	10.28	11.00	15.45
60°	av. size of angle drawn	48.20	52.67	56.57	53.97	53.87	50.33	52.62
	s.d. of angle size	18.42	16.18	15.82	16.23	9.36	9.65	14.73
	av. amount of line variation	29.57	18.03	15.43	16.03	9.58	16.17	17.41
	s.d. of line variation	15.05	14.74	10.17	10.10	6.30	7.98	12.55

TABLE 8--Continued

Angle		Grade 1	2	3	4	5	6	Average
75°	av. size of angle drawn	78.20	68.30	65.73	70.06	63.03	66.33	68.60
	s.d. of angle size	16.79	11.94	19.06	11.88	12.75	12.36	14.96
	av. amount of line variation	21.93	18.93	14.07	16.81	10.87	16.97	16.57
	s.d. of line variation	10.24	14.15	9.47	10.78	6.62	11.60	11.12
90°	av. size of angle drawn	83.63	82.17	85.87	89.00	90.90	91.93	87.29
	s.d. of angle size	14.201	10.94	14.29	13.88	6.77	5.05	11.89
	av. amount of line variation	18.67	15.70	14.87	15.50	9.90	11.17	14.29
	s.d. of line variation	11.185	13.98	16.02	6.46	8.30	7.02	11.27
105°	av. size of angle drawn	100.23	92.80	94.33	106.78	104.97	109.73	101.55
	s.d. of angle size	18.05	16.66	24.88	17.11	10.74	10.57	17.91
	av. amount of line variation	21.27	16.53	10.20	11.72	10.26	14.07	13.96
	s.d. of line variation	20.46	12.80	7.35	8.69	6.13	11.45	12.52
120°	av. size of angle drawn	112.17	95.03	104.07	104.50	108.84	117.07	106.93
	s.d. of angle size	23.11	17.84	20.93	26.82	19.14	9.43	21.23
	av. amount of line variation	25.90	19.50	12.93	13.91	11.94	15.50	16.56
	s.d. of line variation	21.75	14.00	9.63	9.84	9.25	8.51	13.66
135°	av. size of angle drawn	118.97	104.80	113.13	122.81	124.77	126.97	118.66
	s.d. of angle size	23.55	24.48	22.15	14.66	17.95	11.61	20.75
	av. amount of line variation	26.50	24.20	14.33	13.66	12.10	17.17	17.91
	s.d. of line variation	18.38	17.24	10.50	10.16	11.22	8.69	14.05

TABLE 8--Continued

Angle		Grade 1	2	3	4	5	6	Average
150°	av. size of angle drawn	132.67	115.60	120.43	128.84	131.06	135.50	127.39
	s.d. of angle size	25.78	21.06	26.58	27.65	19.28	13.91	23.68
	av. amount of line variation	21.70	21.00	13.73	14.59	15.52	14.23	16.76
	s.d. of line variation	16.12	14.15	9.59	10.80	12.89	9.89	12.71

B. Angles arranged in order, according to how well the size of the angle drawn matched the size of the stimulus angle		C. Angles arranged in order, according to the amount of line variation in the drawings of the angles	
Most accurately copied	90°	Least line variation	105°
	30°		90°
	45°		120°
	15°		75°
	60°		150°
	75°		60°
	105°		45°
	120°		135°
	135°		15°
Least accurately copied	150°	Most line variation	30°

angles. In such a case, any univariate analysis of variance might lead to inflated estimates of significance. Therefore, a multivariate analysis of variance was used in studying these data.

It will be recalled that the data for accuracy of angle copying were in the forms of D-scores. In other words, for each angle drawn, the score is the difference between the size of the stimulus angle which was copied and the size of the angle which the child actually drew. From these ten D-scores, for each subject the following four transformations were derived:

1. the absolute value of the difference between the accuracy with which the right angle was copied, and the average accuracy of copying the acute angles;
2. the absolute value of the difference between the average accuracy of copying the acute angles, and the average accuracy of copying the obtuse angles;
3. the absolute value of the difference between the average accuracy of copying 30°, 45°, and 60° angles, and the average accuracy of copying 15° and 75° angles;
4. the absolute value of the difference between the accuracy with which the 120° angle was copied, and the average accuracy of copying the 105°, 135°, and 150° angles.

The first two test for the relationship in hypothesis 4, which stated that the ability to copy angles would be acquired in the order right, acute, obtuse. The second two transformations ascertain whether there are particular differences among the acute angles and among the obtuse angles in rate of acquisition.

The four transformed variables were first analyzed using the child's grade and order of presentation as independent variables. The Grade x Order

interaction was non-significant,[1] and, given grade in the model, there was no significant effect from order. Hence, order was omitted from subsequent analyses. Given order in the model, grade was found to add a significant effect ($p=.028$), mainly due to differences in accuracy of copying acute, as compared to obtuse, angles.

The mean transformed variable scores are plotted in Figure 19. It can be seen that the second variable score changes the most from grade to grade. These transformed scores are not particularly meaningful numbers by themselves; thus, interpretation of results requires reference to tables of mean scores (for example, Table 8). It then becomes clear that the first graders copied both acute and obtuse angles poorly, making equally large errors copying both kinds of angles. In the second grade the acute angles were copied less inaccurately than the obtuse, with this difference decreasing monotonically through sixth grade. These observations are supported by a significant linear trend, either when the data from all six grades are considered, or when only the data in grades three through six are considered; and a quadratic trend in grades one through four, due to the difference between acute and obtuse.[2] These results support the hypothesis that right angles are acquired before acute angles, and acute angles before obtuse angles.

For the third transformed variable, differences in ability to copy the different acute angles, there is a significant linear trend for grades one through six. This means that some acute angles are acquired at a younger age, while others are differentiated later. On the other hand, none of the obtuse

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[1]The multivariate analyses were performed with the MANOVA program written by Dr. Elliot Cramer from the University of North Carolina at Chapel Hill, described in document no. LSR-108-0 from Triangle Universities Computation Center, Research Triangle Park, North Carolina. All of the MANOVA results for this experiment are listed in Appendix E.

[2]Results from the trend analysis are listed in Table V, parts 1, 3, 4.

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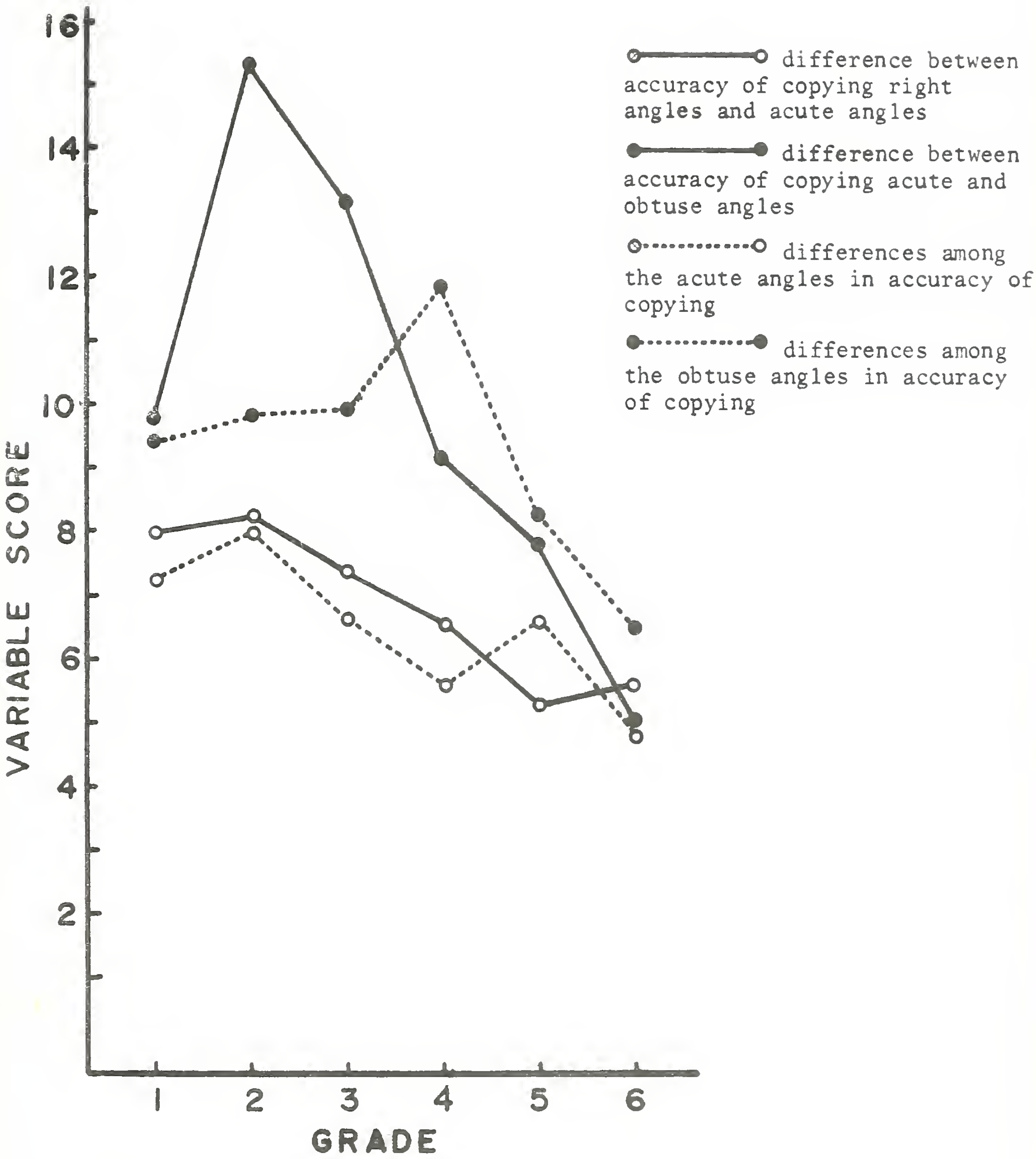

Fig. 19.--Age effect with transformed angle copying variables

angles were very accurately copied by the younger subjects. The greatest differences in accuracy of copying the various obtuse angles occur only after third grade, when some obtuse angles begin to be accurately copied while others still are not. These changes are reflected in the transformed variable for differences among obtuse angles (see Figure 19), for which the difference between the average value of the variable for grades one, two, three, and four and the average for grades five and six approaches significance ($p=.053$).

In a similar analysis using the child's grade and sex, the Grade x Sex interaction was non-significant, while both main effects were significant. As has been discussed, the grade effect was mainly the result of a greater increase from grade one to grade six in accuracy of copying obtuse angles than in accuracy of copying acute angles. The difference between the accuracy of copying acute and obtuse angles was greater for the girls than for the boys. However, as the non-significant interaction indicates, the pattern of results was the same for both boys and girls. Therefore, in subsequent analyses with the angle copying data, treating the sexes together or separately does not affect relationships with other variables.

Histograms were drawn corresponding to each cell in Table 8, showing the distribution of angles drawn for each stimulus angle by children in each grade. Examination of these histograms makes more evident the kinds of copying errors which occur. For the obtuse angles 120°, 135°, and 150°, the distributions of angles drawn by first, second, and third graders all tend to be similar. The size of the angles which they drew ranged from acute angles to a straight line. Fourth, fifth, and sixth graders drew a smaller range of angles for these three stimuli. In each of these distributions, a peak of frequency is evident. This peak was near 120° for the 120° and the 135° angles, and near 135° for the 150° angle. For the 105° angle, a single peak of

frequency appeared at a younger age than it did with the other obtuse angles, although a number of right angles and acute angles continued to be drawn, at all ages, for this stimulus angle.

Although acute angles were drawn when the task was to copy an obtuse angle, the reverse did not occur. The most frequently drawn acute angle was 30°, regardless of the size of the stimulus angle. For the 15° angle, until sixth grade most children drew angles larger than 15°. Younger children drew angles too small when copying the 45° angle, while older children were nearly as accurate for 45° as for 30°. For 60° and for 75°, all children tended to draw angles which were too small. Indeed, older children drew angles of about 52° for the 60° angle with considerable reliability.

A given subject sometimes drew several angles of the same size, in response to different stimulus angles. Angles with the geometrically best line measuring near 30° were the size angle which most commonly occurred three or more times in the drawings of a single subject. Angles whose vertices measure 90° or 45° also were frequently repeated patterns.[1] Younger children showed more tendency to draw a number of angles of a single size, while older children more generally drew the ten different angles differently from each other.

The magnitude of variation of line direction, that is, the difference between the maximum and the minimum angular separation between the two sides of the angle drawing, decreased from grade one through six. There was least variation for angles drawn when the stimulus angle was near 90°. At other times children often used lines which were quite curved (illustrated in Figure 12). There was no systematic relationship between size of angle drawn and amount of linear variation. Bowed angles and angles with two

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[1]Frequencies of occurrence of this phenomenon are tallied in Appendix D, Table I.

vertices were more often drawn when the stimulus angle was acute. Fanned and upwardly oriented angles were more often drawn when the stimulus angle was obtuse. The frequency of occurrence of each of the particular angle drawing aberrations also decreases from grade one through six.[1]

In summary, the hypothesis is supported that 90^{o} angles are acquired first; 90^{o} angles are copied accurately, and with least variability of line direction, by the most children at the youngest age. Furthermore, 75^{o} angles or obtuse angles may be copied as 90^{o} angles. Acute angles are acquired next. Although sometimes they are drawn with considerable line curvature, the different acute angles are drawn differently from each other at a younger age than the obtuse angles are differentiated.

Analysis of the angle matching data was carried out with the same transformations which were used with the angle matching data.[2] The same order of difficulty does not apply to matching angles as to copying them. The angles which were most readily discriminated were 15^{o}, 30^{o}, 90^{o}, and 150^{o}. Two other acute angles, 75^{o} and 60^{o}, were the most difficult of all. It should be noted here again that the 15^{o} and the 150^{o} angles are the smallest and largest on the test, which special quality might in some way contribute to their relative discriminability. Another factor was investigated, namely, whether children picked angles of any particular size more often than they picked other angles, regardless of the size of the stimulus angle. The single angle most frequently selected was 30^{o}. In the lower grades it was chosen equally as often when the 30^{o} angle was not the stimulus angle as when the 30^{o} angle was the stimulus angle. The 90^{o} and the 15^{o} angles, on the other hand, were rarely selected

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[1]See Appendix D, Table II.

[2]Angle matching data are listed in Appendix D, Tables III and IV.

except when they were a correct match. The second most frequently selected angle was the 45° angle, because it was chosen for both the 45° and 60° stimuli. In fact, in grades one, two, three, and five, the 45° angle was picked to match the 60° stimulus more often than the 60° angle was picked. Of the obtuse angles, the 120° angle was the most frequently chosen wrong answer.

In the analysis of variance of angle matching accuracy with grade and order as independent variables, the Grade x Order interaction was significant ($p=.01$),[1] for the most part due to the difference between acute and obtuse. The main effect for grade, significant at $p=.001$, appears more dominant than the interaction. The source of the grade effect is the difference between acute and obtuse angles and differences among obtuse angles. There were no effects from order. A plot of the scores for the interaction suggests that the first and third grade subjects got more acute than obtuse angles correct when they were given the orders of presentation which began with acute angles, while first and third graders who were shown obtuse angles first got more obtuse angles correct and hence had a smaller difference between acute and obtuse. Older subjects were not affected by order of presentation and consistently discriminated acute angles better than obtuse.

In the analyses with grade and sex as independent variables, neither the main effect due to sex nor the interaction was significant.

The question of most interest about the angle matching data is the extent to which a child's ability correctly to discriminate an angle accounts for his ability to draw it. To answer this question, the angle copying data were again analyzed, this time covarying the angle matching data. Essentially this technique computes the correlation between angle matching and angle

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[1]Angle matching analyses are in Appendix E, beginning with Table III.

copying, subtracts this effect, and analyzes the remaining variance for differences in angle copying. The regression of angle matching on angle copying proved to be non-significant. With angle matching covaried, there were still significant grade effects for angle copying.[1]

The parallel lines data include: the difference between the orientation of lines which were drawn and the orientation of stimulus lines, the standard deviation of this difference score; the angular separation between the pair of lines, the standard deviation of the separation score.[2] Within almost every grade the horizontal lines were the easiest and the diagonal lines were the most difficult to copy. In order to test for the hypothesized difference between acquisition of the ability to draw horizontal and vertical lines which are parallel and diagonal lines which are parallel, a single transformed variable was derived:

5. the absolute value of the difference between the average angular separation for horizontal and vertical lines and the angular separation for diagonal lines.

Analysis of this new parallel lines variable by grade and by order of presentation yielded a non-significant order effect and a significant effect due to grade. The interaction could not be computed, because two orders of presentation were inadvertently omitted from the third grade data collection. In the analysis by grade and sex, the interaction was significant, while the main effect due to sex was non-significant, and the grade effect, given sex in the model, was significant. Here again the main effect appears more important than the interaction. Over all of the scores there is a significant

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[1]Compare parts 1 and 2 of Table V, Appendix E.

[2]Parallel lines data are presented in Table V in Appendix D, and the relevant analyses are summarized in Tables VI and VII in Appendix E.

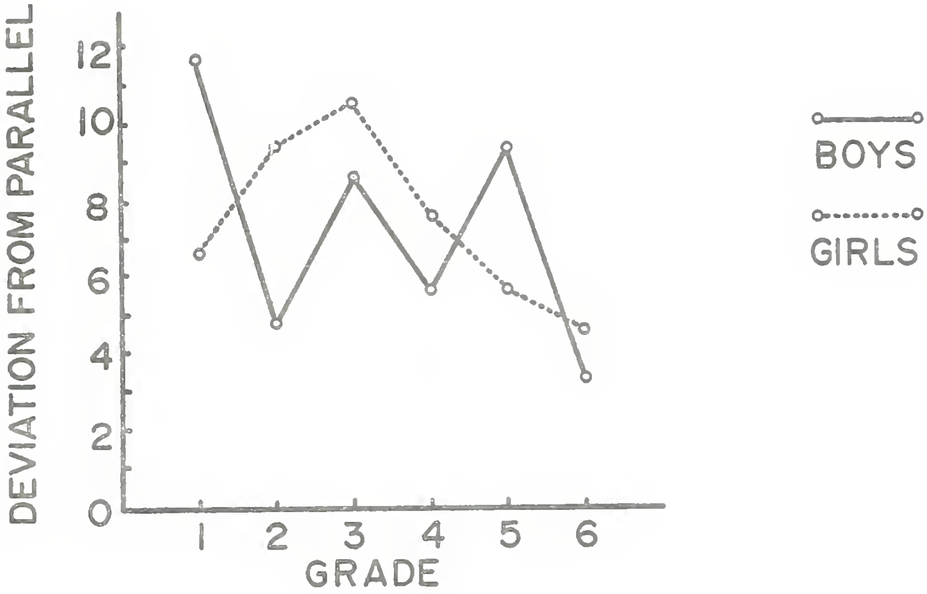

Fig. 20.--Sex effect with transformed parallel lines variable

linear trend and a significant difference between grades one through four and grades five and six.[1] The graph showing the mean scores for boys and girls at each grade is given in Fig. 20. It can be seen that the boys's scores fluctuate considerably from one grade to another. This pattern can be partially accounted for by a significant regression of IQ on parallel lines ability (p .05).

In summary, the hypothesis is supported that drawing two lines parallel to each other is more difficult when they are diagonal. Pairs of horizontal and vertical lines were drawn more nearly parallel to each other by children at a younger age. Older children's ability to draw parallel lines was less dependent on line direction.

The final question of interest in this experiment is the extent to which a child's ability to copy these graphic elements is predictive of his

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[1]Results from the trend analysis are listed in Table V, parts 1, 3, and 4, in Appendix E.

stage of cube drawing. Covariance procedures were used to determine whether differences in level of skill with the graphic elements shown by children from the different grades accounted for differences in their cube drawing stages. The regression of all five transformed variables on stages of drawing the solid cube was not significant.[1] Likewise, neither the regression of the five variables on stages of copying the oblique projection, nor the regression of the five variables on stages of copying the isometric projection, was significant. This result means that children's cube drawing stage is determined for the most part by factors other than skill at drawing the individual graphic elements. Skill at copying graphic elements, did, however, account for individual differences in stage of copying the oblique as opposed to isometric projection,[2] and for sex differences in stage of drawing the solid cube.

The detailed interplay of cube stages with specific graphic elements was further studied by means of the following tactic. Subjects were grouped according to the stage of their cube drawing, enabling examination of the level of acquisition of each of the graphic skills for children of each stage. In the analyses performed on the basis of these comparisons,[3] it was found, for the task of drawing a picture of a solid cube, that there was no particular increase in graphic skills associated with the transition between stage 1 and 2. However, cube matching ability differed between stage 1 subjects and all other subjects and between stage 2 subjects and stage 3 and 4 subjects. For the task of copying oblique or isometric projections, the difference between stage 1 and 2 subjects and higher stage subjects was due to differences in

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[1]See Table IX in Appendix E.

[2]See Table X in Appendix E.

[3]See Table XI in Appendix E.

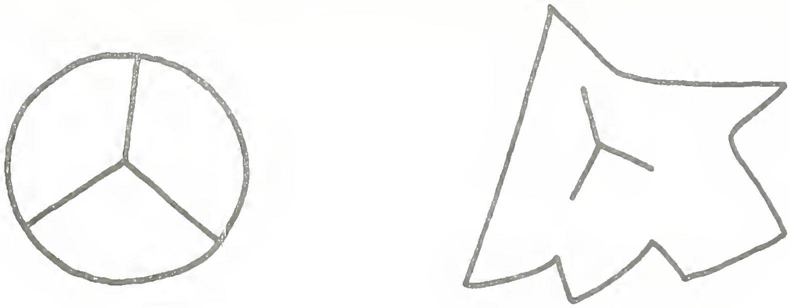
accuracy of copying right as compared to acute angles, and to differentiation of acute and obtuse angles. Subjects who drew stage 3 and stage 4 pictures of the solid cube differed the most in accuracy of copying parallel lines. On the other hand, children who copied oblique or isometric projections at stage 4 as compared to stage 3 were best differentiated by the inadequacy of their cube and block matching performance.

This post hoc analysis suggests that, to the extent that there is some association between the stage of a child's cube drawing and his skill at copying angles and parallel lines, (a) the development of different particular abilities becomes important at different stages of the cube drawing sequence, and (b) the level of ability to portray a solid cube and ability to copy a picture of a cube are dependent upon somewhat different skills. Moreover, for drawing the solid cube, the strength of the association between the solid cube and its two-dimensional projection is important at younger ages; whereas, stage of copying the oblique or isometric projection, or stage of older children's drawings of the solid cube, is more closely related to level of ability with individual graphic elements.

3. Experiment 3

The mock-cubes drawn by Pearson School subjects were scored by the same criteria as the cube drawings. Stages 3, 4, and 5 for the mock-cube were indistinguishable from comparable stages for the cube drawings. Less advanced drawings of the mock-cube took on unique forms, exemplified by the illustrations in Figure 21, and did not resemble cube stages 1 and 2. One of the raters was familiar with the mock-cube experiment, while the other believed that he was scoring regular cube drawings.[1] Inter-rater agreement

[1]Svea Oster Katz was the informed rater, and Mark Salomon was the naive rater.



A. B.

Fig. 21.--Drawings of the mock-cube less advanced than stage 3

was 96 per cent for stage scores, and 91 per cent for substage scores.

The frequencies with which mock-cubes were drawn at these less advanced stages and at stages 3, 4, and 5 were compared to the frequencies of usage of the different stages for drawing the three actual cube stimuli.[1] Children were relatively competent at the mock-cube task. The frequency with which children in each grade produced stage 4 and 5 drawings was greater when they were drawing the mock-cube than when they were drawing actual cubes. Examination of the average drawing stage in each grade for each stimulus shows that in grades four, five, and six the mock-cube was drawn at a higher stage than any of the three cube stimuli. For the other grades, the pattern was a little more complicated. Over 80 per cent of the first and second graders drew the solid cube at stage 1 or 2, while the modal stage for copying the oblique or isometric projection was stage 3, and 50 per cent of the mock-cube drawings were at stage 3, 4, or 5. Results for the third graders follow essentially the same pattern, except that the oblique and isometric projections, like the solid cubes, were sometimes drawn like Necker cubes. In all of these grades, however, the average stage of the mock-cube drawing

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[1]Frequency tables for cube and mock-cube drawings, a comparison of stage usage, and average scores for children in each grade on each of the tasks are presented in Appendix B. Analyses of variance involving the mock-cube stages are summarized in Appendix C.

exceeded that of the solid cube. Some typical children's drawings are shown in Figure 22.

These results support hypothesis 7, that children can successfully draw a cube unintentionally, by copying a mock-cube, before they perform equally as well on the task of drawing a cube. Furthermore, in each grade, the boys drew the mock-cube significantly better than the girls. The following additional analyses, carried out with the mock-cube data, elaborate on the relationships between mock-cube drawing and the other tasks.

In the previous section it was observed that the stage of a child's cube drawing could not be predicted from his level of skill at copying graphic elements. For the mock-cube, however, the regression of the five transformed copying variables on the stage of the drawing was significant,[1] although not entirely accounting for the variance due to grade and sex. The most important copying variables for predicting mock-cube stage were differentiation of acute angles and accuracy of parallel lines. In another set of analyses, the children's scores on the Children's Cubes Scale were covaried with their cube drawing and mock-cube drawing stage.[2] The Children's Cubes Scale score, while significantly related to cube drawing stage, was found to account for little of the variation among subjects of different ages for any of the three tasks which involved drawing actual cubes. In contrast, for drawing the mock-cube, there was no significant grade effect except for the variance attributable to differences in performance on the Children's Cubes Scale. These results indicate that drawing the mock-cube is a task which presents to the child both elemental and strategic sorts of graphic difficulties characteristic of cube drawing, apart from the context of drawing a picture of a cube.

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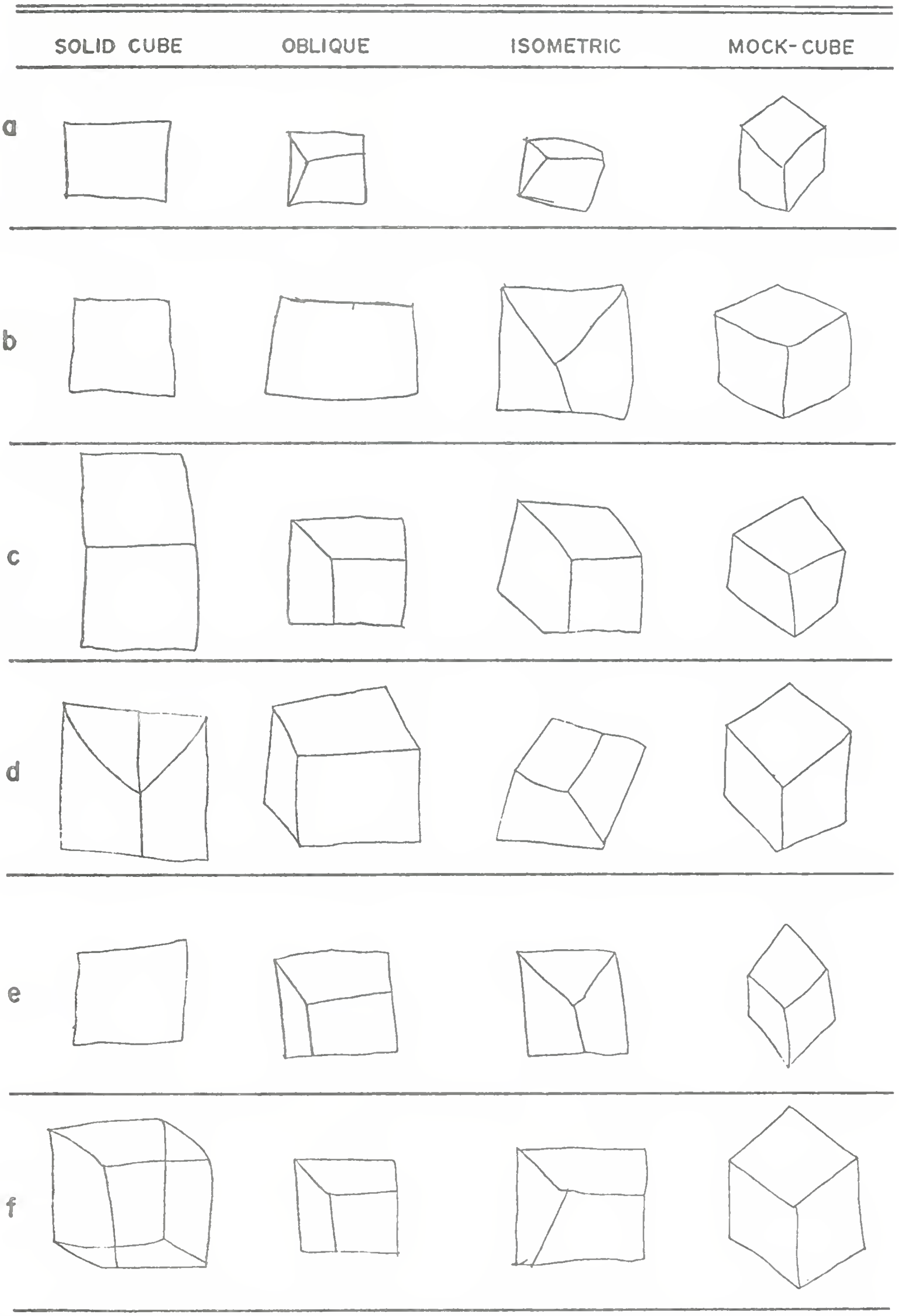
[1]Appendix E, Table IX.

[2]Appendix C, Table VII.

Fig. 22.--Sample cube drawing protocols. Reduced 4X.

Each row contains the productions of one subject:
the picture he drew of the solid cube,
his copy of the oblique projection,
his copy of the isometric projection,
his drawing of the mock-cube.

The subjects are Pearson School students:
a = DD, a first grade male,
b = JM, a fourth grade female,
c = MB, a fourth grade male,
d = JB, a fourth grade female,
e = SC, a fifth grade female,
f = HA, a sixth grade female.


SOLID CUBE
OBLIQUE
ISOMETRIC
MOCK-CUBE
a
b
c
d
e
f

B. T. Harry Garrett School

A total of eighty-two white, middle-class subjects from grades one, three, and five were seen at T. Harry Garrett School. These data were analyzed in an attempt to replicate the major findings from the Pearson School data. Further, analysis of the Pearson data had led to some unexpected results. The T. Harry Garrett data were examined to determine if the same results obtained. In particular, I was concerned to know:

1. whether the sequence of stages for drawing the solid cube and copying the oblique and isometric projections was the same at both schools;
2. whether the pattern of sex differences was the same, namely, boys perform better than girls on drawing the solid cube, copying graphic elements, and drawing the mock-cube;
3. whether order of presentation of the solid and two-dimensional cubes affected stage of drawing the solid, as happened with the Pearson School subjects;
4. whether the Children's Cubes Scale score in this case also was more strongly related to mock-cube stage than to actual cube stage;
5. whether ability to copy graphic elements was related to the stage of the cube drawings in the same way as with the Pearson School group;
6. whether there were any significant differences between the two groups in overall level of performance.

1. Stages of Cube Drawing

In general, the hypothesized developmental sequence is again supported. Contingency tables for the substages of cube drawings for the T. Harry Garrett subjects are presented in Table 9. Scoring by substage rather than by stage

TABLE 9

SUBSTAGES OF CUBE DRAWING, T. HARRY GARRETT SCHOOL

Grade	Substages 1	2a	2b	3a	3b	4a	4b	5
A. Drawing a solid cube								
1 (N = 23)	.35	.22	.13	.13	.09	.09	.00	.00
3 (N = 29)	.10	.21	.00	.07	.31	.10	.21	.00
5 (N = 30)	.17	.23	.00	.03	.07	.07	.40	.03
Total	.20	.22	.04	.07	.16	.08	.22	.01
B. Copying the oblique projection of the cube								
1	.04	.00	.13	.13	.61	.04	.04	.00
3	.00	.10	.00	.07	.24	.07	.48	.03
5	.00	.07	.00	.10	.17	.03	.55	.07
Total	.01	.06	.04	.10	.32	.05	.38	.04
C. Copying the isometric projection of the cube								
1	.04	.09	.00	.04	.70	.00	.09	.04
3	.00	.03	.00	.03	.38	.07	.45	.03
5	.00	.07	.00	.10	.27	.00	.43	.13
Total	.01	.06	.00	.06	.43	.02	.34	.07

alone again added little information. In particular, there was no age at which there was a strong emergence of stage 4a drawing, as happened in the Pearson third grade.

The subjects from T. Harry Garrett, like the Pearson subjects, tended to draw more stage 4 and 5 pictures for the mock-cube than for the other three cube stimuli.[1]

The Children's Cubes Scale figures from T. Harry Garrett were scored right or wrong by the same criteria as the Pearson School figures. The items were found to form a Guttman scale with a reproducibility of .89. However, the order of difficulty of the figures was not identical for the two samples, primarily because the T. Harry Garrett subjects, on the whole, found the designs equivalent to stage 2b to be more difficult to copy than the 3a designs (see Table 10). With this exception, the overall ordering of the figures was quite similar, as indicated by a Spearman rank order correlation coefficient of .92 between the two sequences.

2. Sex Differences

In the analyses for sex effects, differences between boys and girls in stage of drawing the solid cube did not quite achieve significance. For copying the oblique projection, there was a significant sex effect, although of less magnitude than the grade effect.[2] This pattern of results is the reverse of the pattern of sex effects for the Pearson School data.

Analysis of the T. Harry Garrett mock-cube data revealed significant grade and sex main effects. The boys drew the mock-cube a good deal better than the actual cubes, while the girls drew it only slightly better.

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[1]Additional data tables pertinent to Experiments 1 and 3 are in Appendix F.

[2]See Appendix F, Table V.

TABLE 10

T. HARRY GARRETT SCHOOL CHILDREN'S CUBES SCALE DATA

		Grade 1	3	5	Average Score for the Design
	Av	1.0	1.0	1.0	1.0
	Av	1.043	1.034	1.033	1.036
	Av	1.130	1.0	1.033	1.049
	Av	1.217	1.0	1.067	1.085
	Av	1.391	1.069	1.033	1.146
	Av	1.565	1.103	1.067	1.220
	Av	1.609	1.034	1.167	1.244
	Av	1.609	1.241	1.067	1.280
	Av	1.522	1.241	1.167	1.293
	Av	1.826	1.379	1.433	1.524
	Av	1.826	1.414	1.533	1.573
	Av	1.826	1.655	1.500	1.646
	Av	1.956	1.586	1.467	1.646
	Av	2.0	1.828	1.733	1.841
	Av	1.956	1.931	1.767	1.878
Average Score for the Grade		1.565	1.301	1.271	1.364

For copying angles and parallel lines, neither sex nor Grade x Sex was significant.[1]

In summary, while effects due to the children's grade level were replicated, sex effects were not.

3. Order of Presentation

Analysis of the solid cube drawing stages by grade and order of presentation revealed no effect due to order.[2] Thus, the Pearson School results with respect to order of presentation were not replicated.

4. Relationships between the Children's Cubes Scale and Other Variables

The correlation of the Children's Cubes Scale score with the children's stages of cube drawing was .53, .60, and .55 for the solid cube, the oblique projection, and the isometric projection, respectively. This is a slightly larger correlation than was found with the Pearson School data.

In covariance analyses with the Children's Cubes Scale, variations in the stage of mock-cube drawing in the different grades were accounted for, as happened with the Pearson School data. However, due to the generally greater association between the Children's Cubes Scale and cube drawing stage for subjects from T. Harry Garrett, their Children's Cubes Scale score also accounted for the grade effect for drawing the solid cube, grade and sex effects for the oblique projection, and the grade effect for the isometric projection.[3]

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[1]See Appendix G, Table IV.

[2]See Appendix F, Table IV.

[3]The Children's Cubes Scale data are presented in Tables II, III, and VI in Appendix F.

5. Predicting Cube Drawing from the Ability to Copy Graphic Elements

Covariance procedures were used to assess the extent to which a child's ability to copy the graphic elements was predictive of his cube drawing stage. With the T. Harry Garrett data, like the Pearson data, the regression of the copying variables on stages of solid cube drawing, copying the oblique projection, and copying the isometric projection was non-significant. Sex differences in copying the oblique projection were not accounted for by differential ability with graphic elements.

Covariance analysis further indicated that the five copying variables were significantly related to stage of mock-cube drawing. Unlike the Pearson results, in addition to the significant regression effect, the main effects due to both grade and sex remained significant.

Analysis of the graphic elements using stage of cube drawing as the independent variable replicated few of the Pearson results, possibly due to the unevenness caused by most of the T. Harry Garrett subjects having drawn stage 3 and 4 cubes.[2]

In summary, elementary grapho-motor abilities were even poorer predictors of cube drawing stage at T. Harry Garrett than with the Pearson School subjects.

6. Differences between the Two Samples

For the cube drawing tasks, comparison of the stage data for Pearson and T. Harry Garrett, plotted in Figure 23, shows that the T. Harry Garrett children were slightly more advanced than the Pearson School children, except for the fifth grade T. Harry Garrett children, who were scarcely better than

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[1]See Table VI in Appendix G.

[2]See Table VII in Appendix G.

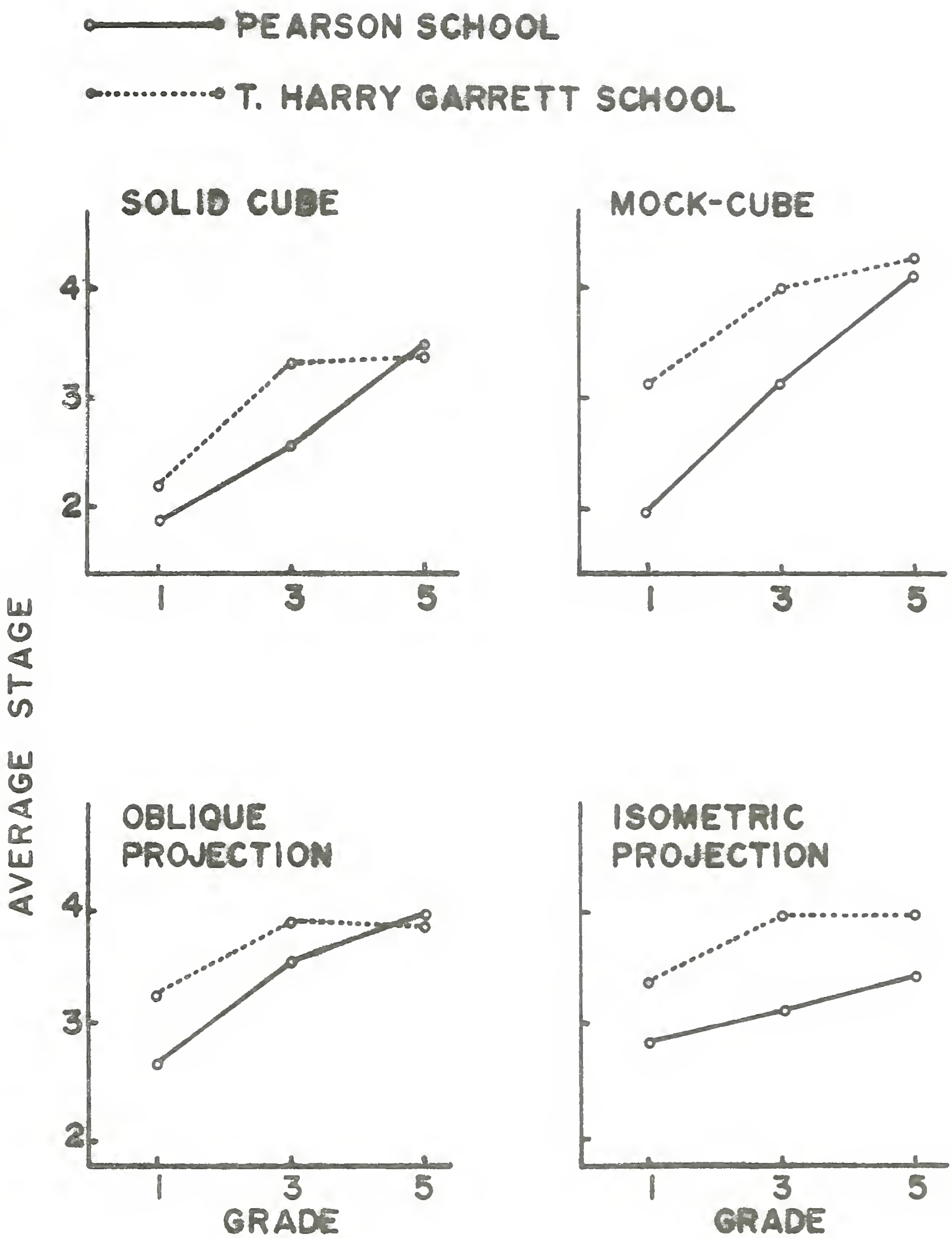

Fig. 23.--Average cube drawing stage, Pearson vs. T. Harry Garrett

the T. Harry Garrett third graders on the solid and oblique tasks. One explanation for this effect is that the T. Harry Garrett third graders had a significantly higher average IQ than the T. Harry Garrett fifth grade subjects. Analysis of variance for each of the three tasks suggests that the difference between the two schools is significant only for copying the isometric projection.[1]

T. Harry Garrett children drew the mock-cube significantly better than the Pearson School children.

On the cube and block matching tasks, the percentage of children making each choice was quite similar in the T. Harry Garret subjects and the Pearson subjects. The frequencies for the T. Harry Garrett subjects are presented in Table 11, for comparison with Tables 4 and 5. Analysis of variance of the scores revealed no significant difference for the two schools, although there was a significant grade effect.

In an analysis of variance of the Children's Cubes Scale scores for the two schools, it was shown that the T. Harry Garrett students did significantly better than the Pearson students. The average score for the T. Harry Garrett first graders was close to the average score for the Pearson second graders, the T. Harry Garrett third graders did better than the Pearson fourth graders, and the fifth graders at both schools performed similarly.

The approximate magnitudes of the scores and the patterns of results for angle copying and angle matching were the same for the T. Harry Garrett subjects as for the Pearson subjects.[2] For accuracy of copying parallel lines, there were some differences. T. Harry Garrett subjects were more accurate with

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[1]All analyses comparing the two schools are summarized in Appendix H.

[2]Compare Tables I, II, and III in Appendix G with Table 8 and Appendix D.

TABLE 11

CUBE AND BLOCK MATCHING FREQUENCIES,
T. HARRY GARRETT SCHOOL

Picture Selected as the Best Picture of the Solid Cube					
Grade	First Choice: Oblique Projection	First Choice: Square	Second Choice, When First Choice was Square: Oblique Projection	Second Choice, When First Choice was Square: Other	First Choice: Other
1	.44	.39	(.26)	(.13)	.17
3	.59	.34	(.20)	(.14)	.07
5	.60	.30	(.27)	(.03)	.10

Block Matching

Grade	Cube	Mock-Cube	Square	Other
Block selected when presented the oblique projection to match				
1	.74	.00	.17	.09
3	.90	.00	.07	.03
5	.87	.07	.07	.00
Block selected when presented the isometric projection to match				
1	.70	.13	.09	.09
3	.76	.10	.03	.10
5	.77	.20	.03	.00
Block selected when presented the line drawing of a square to match				
1	.26	.00	.74	
3	.03	.00	.97	
5	.13	.00	.87	

vertical than with horizontal lines, and least accurate with diagonals, whereas the order of difficulty for the Pearson subjects was horizontal, vertical, diagonal. Grade-by-grade comparison of T. Harry Garrett subjects with the Pearson subjects shows that the T. Harry Garrett subjects drew vertical and diagonal lines more accurately than Pearson School children did.

In summary, the white, middle-class subjects excelled in the grapho-motor tasks. The overall developmental sequences appeared to be the same, and there was no difference between the two groups in solid cube drawing or in cube matching.

V. DISCUSSION AND CONCLUSIONS

This study has delineated the steps by which children acquire the ability to represent a solid object. In this discussion I will first review the developmental sequence of cube drawing stages which was established in Experiment 1. I shall critique these results and briefly consider how this study relates to some theoretical problems concerning models of developmental sequences. Second, because cube drawing is regarded as exemplary of the general problems of representation of a three-dimensional object in two dimensions and reproduction of complex line drawings, I shall seek to show some ways in which the results of this study fit with and amplify findings in both of these areas. With regard to the latter issue, how the results of Experiments 2 and 3 contribute to the understanding of cube drawing difficulties will be discussed. At this point also the significant sex differences found in this study will be taken up. Finally, I will review the important results from all of the experiments and attempt to clarify the emerging picture of the interweaving of grapho-motor and conceptual problems which children must overcome in order to draw a picture of a cube.

A. The Developmental Sequence

The results of Experiment 1 confirm that the cube is difficult for elementary school children to draw, and that acquisition of the ability to draw a cube is characterized by the appearance of distinguishable stages. Correct perspectival representations of the cube were obtained from children as young as seven, but only 50 per cent of the eleven to twelve year olds had mastered the task. Among the other children's attempts to draw a cube, and

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among their attempts to copy the oblique and isometric projections of the cube, characteristic forms appeared. The occurrence of these forms is correlated with the age of the children, and the developmental sequence thus established is concordant with the hypothesized stages. The same procedure for discerning an age-related sequence was carried out on a second independent sample of elementary school children, of a different social class and race, and again the same sequence was evident. The drawing forms which characterize each of the stages, illustrated in Figures 4 and 16, are (1) a square, (2) a combination of squares, (3) a figure which includes diagonal lines, (4) a figure which includes parallel diagonal lines, and (5) a correct perspectival representation of the cube.

More than five categories of cube drawings were apparent among the children's attempts to draw a cube. Therefore, substages were defined, to see whether the developmental sequence might thereby be refined. Within stages 2 and 3, figures with a square outline (substage _a_) were distinguished from juxtaposed figures which did not have a square outline (substage _b_). Within stage 4, transparent or superimposed figures such as the Necker cube (substage _a_) were distinguished from juxtaposed figures (substage _b_). When these were tested for developmental significance, substage 3b appeared to be more advanced than substage 3a. Distinguishing substages for stages 2 and 4 does not contribute to the developmental sequence, although the import of the distinctions remains of interest and will be discussed in the following section. Substages 2a and 2b had been differentiated on the basis of whether the outline of the completed picture was square. There are two possible explanations for why this particular distinction made little difference: (a) this classification was made on the basis of the shape of the outline of the completed figure, while perhaps it should have been made on the basis of the child's drawing technique;

or (b) this distinction may not have been the most appropriate one, and perhaps what should be distinguished among stage 2 drawings is whether they have three parts, fewer parts, or more parts. These alternative substage scoring schemes, however, could best be explored further with a larger sample of younger children.

With the stage 4 substages the problem was the scoring of the Necker cube, because it is a trained rather than naive response. A child generally said that an older sibling, a grandmother, a classmate, or a teacher had showed him how to draw a Necker cube, by superimposing two squares and connecting corresponding corners. The discrepancy between the quality of the child's rote graphic production and his own understanding of the task of drawing a cube probably explains why it is difficult to place the Necker cube in the developmental sequence. Some clarification might be provided by asking these children to draw the cube a second way as well.

Because of the experimenter's difficulty in classifying the Necker cube drawings, they may have been over-rated. To illustrate this problem, recall that the Pearson third graders drew cubes at a higher stage than the fourth graders, which effect was even more pronounced for the girls than for the boys. While the fourth graders drew slightly more stage 1 cubes than would have been predicted from second grade levels of response, the most striking difference was the high number of stage 4a responses among the third graders as compared to those of the fourth graders. This apparent reversal, then, might be, at least in part, an artifact resulting from over-evaluation of the Necker cube drawings.

B. Models for Developmental Processes

The five stage developmental sequence by which the cube drawings were scored is an example of one particular kind of model for developmental change,

called a simple unitary progression by van den Daele (1969). Consideration of other models for describing developmental change has been encouraged by van den Daele and by others, such as Coombs (1972). Two particular alternatives to simple unitary progression might apply to interpretation of the cube data:

1. There may exist a number of alternative but equivalent courses of development, called multiple progressions or pathways. For example, one child might move from stage 1 to 2b to 3b, while another might move from stage 1 to 2a to 3a.

2. More than one alternative might be within an individual's repertoire at any point in time. In this case, the nature of the cube stimulus might determine which drawing response occurred, for example, the same child might draw a stage 4b picture of a solid cube and a stage 4a picture when asked to draw a "box."

Either of these interpretations would help to explain the failure of substage distinctions to improve upon the age-relatedness of the developmental sequence defined by stages alone. Longitudinal data would be useful in clarifying these issues. Observation of a single child's productions before and after instruction in cube drawing would also help in exploring the nature of the progression.

The problem of defining developmental change involves an additional issue. Langer (1969) defines a general developmental perspective, exemplified by Piaget and Werner and Kaplan, which he calls "organic lamp" theory. Essential to this model is the existence of a universal and invariant sequence of stages, which meets the additional criterion that the attainment of each new stage involves the integration of elements from the previous stage into a qualitatively different new response. Thus, establishing that a set of

forms constitutes an age-related sequence, by empirically ordering the stages according to the children's grade in school, is only one part of demonstrating that the forms represent developmental stages. One must also answer the question of whether attainment of each stage presupposes mastery of all previous stages. As emphasized by Kugelmass and Breznitz (1967), who agree that this feature is critical to Piaget's theory about stage sequences, it can be tested by application of Guttman scalogram analysis to an a priori selection of items representing the different stages of development. This paradigm was precisely the procedure applied in establishing the Children's Cubes Scale analysis. All of the subjects copied cube forms characteristic of all of the different stages. The essential features of the developmental sequence were validated by the ordering of the Children's Cubes Scale items, although there was not complete agreement on the normative age for attainment of each stage. These results establish that there is a general age-related sequence of qualitatively different cube forms, and that children at each stage are capable of producing responses characteristic of all lower, prior, stages. Thus, we can say that the cube forms which illustrate each step of the age-related sequence also fit the definition of developmental stages.

C. Drawing Solid Objects

In the preceeding section some general models of development were considered. In this section I will focus on a few points relevant to how the forms which constitute the developmental sequence elucidated in this study are related to sequences for the development of children's drawings of human figures and other objects, described by other authors. The progression described by Luquet and restated by Piaget and Inhelder, the progression described by Burt (1927), and the sequences presented in early German studies surveyed by Harris (1963) are similar in that each proposes approximately the same three stages for

the elementary school years. These stages have some parallels with the stages of cube drawing.

Children aged five to six are in a stage which Luquet calls "synthetic incapacity" and Burt refers to as "descriptive symbolism." The import of these labels is that the children's drawings are not thought to be deliberately schematic, but rather to result from reduction of details and limited concern for shape and proportion. Although lack of control over their graphic movements may prevent the youngest children from giving their lines the appearance they want, even more important is their limited capacity for sustained attention:

> Although in visual perception of the object he apprehends the whole group of elements and their interrelations, in successive and discontinuous representation when he is drawing them, their relationship escapes him: he knows it but he does not think about it.[1]

Both a stage 1 cube and a cube whose different parts were drawn disjunctively rather than touching would exemplify this stage. Indeed, a disjunctive cube was drawn, but only in one particular condition, namely, when stage 1 children drawing the colored cube were asked to portray more colors than one.[2] It should be noted as well that stage 1 cubes, contrary to expectation, remained quite frequent as representations of the solid cube up to age ten. This result will be discussed in more detail later.

In the following stage, termed "intellectual realism" by Luquet, drawings are still symbolic rather than realistically depictive. Children's drawing techniques during this period include: <u>multiple vantage points</u>, which could lead to stage 2b productions; <u>transparency</u>, which category might include stage 4a; and <u>flattening</u> on to a single horizontal plane. Evidence that this

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[1] G.-H. Luquet. <u>Le Dessin Enfantin</u>. Paris: Libraireie Felix Alcan, 1927. translation from Sect. 66.

[2] The colored cube task is described in Appendix I.

last technique, which is like viewing an object from far above it, might account for stage 1 productions, particularly in older children, is provided by the colored cube task. When children who drew a square were asked which color they had drawn, some younger children appeared not to understand the question. However, the majority of children answered that they had drawn the top face of the cube.

The next stage, placed by Burt at age ten to eleven, is called "visual realism" by both Luquet and Burt. The child no longer draws from memory and imagination, instead, he tries to represent the object.

> The increasing demand for realism brings with it a great improvement in technique...There is an effort to portray the external semblance of the object as it is seen by an unsophisticated vision.[1]

Forms from stages 4b and 5 are examples of visual realism. Precisely where in this sequence the stage 3 drawings fit is not obvious. Some 3b pictures may be attempts at representing what the child sees from a single vantage point. A stage 3a drawing of a solid cube, however, because it is based on a square outline, seems to be more symbolic than realistic.

A second perspective from which to view the nature of the developmental sequence of cube forms established in this study is Werner's (1948,1963) theory of mental development. Stage 1 and 2 cubes would exemplify some aspects of the child's primitive perceptual-motor organization. Werner contends that the child perceives objects in terms of physiognomic rather than geometrical properties, and that his earliest depictions are global and expressive. According to this viewpoint, when a child draws a square, he is expressing the most salient global quality of the cube. At stage 2, the drawings exemplify Werner's homogenization of directions and parts, expressing in each of the parts the qualities of the whole. A 2b drawing, which Werner places at age six

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[1]C. Burt. Mental and Scholastic Tests. London: P. S. King and Son, 1927. p. 321.

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or seven, is not organized around one comprehensive aspect, but is like a collection of global units. In later stages, children's drawings of cubes show increased differentiation, and organization around a single conceptualization.

D. Figure Copying

Rather than studying cube drawing as a problem of representation of a solid object, others have focussed on the task of copying a line drawing of a cube. This is the approach taken by Lurcat, and by researchers in the area of organic brain damage, for example, Hacaen and Assal (1970). As mentioned, very nearly the same forms appear in children's copies of the oblique projection as in their attempts to draw a cube directly from the solid. The sequence we observed for children's attempts to draw the solid cube is similar as well to the stages found by Lurcat for children's attempts to copy an oblique projection. Lurcat, however, did not discuss in any depth the relationship between the developmental stages for cube copying and more general figure copying problems. It was for this purpose that Experiment 2 was devised.

A few aspects of figures have been consistently found harder to copy than other aspects. A diamond is a more advanced Stanford-Binet figure than a square. Gesell and Ames (1946) showed that a triangle is more difficult to draw than a square. Graham, Berman, and Ernhart (1960) suggested that changes in line direction correlated with difficulty of figures. More recently, Olson again pointed to the relative difficulty of constructing diagonal lines. Consistent with these studies, in this study it was found that right angles are drawn sooner than acute and obtuse angles, and that it was most difficult to draw lines parallel when the direction of the lines was diagonal. Furthermore, the same order of acquisition of the particular graphic skills was observed both when they were isolated productions and when they were drawn

incorporated within complex figures. For example, cube forms which contain only right angles constitute stages 1 and 2, and two diagonal lines drawn nearly parallel do not appear in copies of a drawing of a cube until stage 4.

In one previous study comparing the task of copying a 41° angle by itself and the task of copying the same angle when it was a part of a figure, in this case, a parallelogram, Campbell[1] found some interesting differences. While the angle by itself was copied particularly accurately by four to six year old children, within the parallelogram the same 41° angle was reproduced like a right angle. Harris regarded this result as evidence of the influence of a cognitive bias of the children toward apprehension of a figure in terms of something familiar to them. In other words, the children, who were familiar with squares and rectangles but not with parallelograms, drew the shape with which they were familiar, and which was easier for them to draw. According to Harris's precis of relevant research, figures which are too difficult are the most likely to be simplified. If a figure is entirely meaningless to the child and not too difficult for him to draw, however, a child will copy it precisely.

It will be noted that Harris's concept of a cognitive bias has the same functional significance as Luquet's concept of an internal model. In either case, the expectation is that, if the child regards a figure as an instance of a particular internal model, then he will perform the task of copying that figure by, in fact, drawing his internal model.

Some of the systematic errors which were observed in the angle tasks might be interpreted within this framework. In particular, the 60° angle was drawn closer to 50° than to 60°, by children at all ages, and was matched with the 45° angle as often as with the 60° angle. Examination of the alphabetic letters which these children had been taught to write showed that the sides of

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[1]D. T. Campbell, personal communication, in D. B. Harris (1963).

the capital "Y" and "V" have an angular separation of about 50^{o}, and the sides of the "A", of about 45^{o}. The children sometimes remarked as they drew the right angle about its similarity to the letter "L." Likewise, they mentioned that the acute stimulus looked like an "A" or "V." Perhaps, then, mastery of a similar figure leads a child, given a new stimulus, to draw that with which he is familiar and which he is accustomed to draw.

E. The Influence of the Associative Value of Patterns upon the Copying of Forms

Skill with individual graphic elements accounted for only a small proportion of individual differences in drawing a solid cube or in copying oblique or isometric projections of a cube. On the other hand, skill with individual graphic elements did account for individual differences in drawing the mock-cube, which also was drawn better than any of the actual cube stimuli. In the case of copying the two-dimensional projections, possibly the association of the two-dimensional pictures with the notion of the solid cube leads children to copy the two-dimensional projections with some of the same errors as appear in their drawings of the solid cube; in other words, to draw from their internal model of the cube instead of trying to copy the picture of the cube which is in front of them. The hypothesis that children look at the two-dimensional cube stimulus and then summon an appropriate internal model receives informal support from the children's comments during the session. When they were asked to copy the two-dimensional projections, children frequently remarked, "That's a box," or "Oh, it's another box," before beginning the drawing. In contrast, after fully completing the drawing of the mock-cube, many children paused an instant, looked at their own work in amazement, and exclaimed, "I just drew a box." After that recognition had occurred, a number of children spontaneously attempted to draw another picture of the cube by

trying to repeat what they had done on the mock-cube task.

While the results with the mock-cube suggest that ease of drawing it was due to its relative freedom from accustomed associations, one other possible explanation must be considered. It has to do with strategy of drawing. Copying is step-wise action. The mock-cube, because of its structure, seems to help to provide the steps, specifically, (1) drawing the wooden hexagon, (2) filling in the internal lines. This contrasts with copying the two-dimensional cube projections.

F. Sex Differences

There was a confusing pattern of differences between male and female subjects in their drawings. The middle-class, white sample showed male-female differences in stage of copying the oblique projection of the cube, the boys performing at a higher level than the girls. These results are consistent with the report by Leroy (1951) that, when drawing a variety of objects, girls attempted to show the objects in perspective as often as the boys did but their attempts were poorer. More generally, the results of this study are in agreement with the superiority usually attributed to boys in the intellective factor which includes spatial, mechanical, and manual abilities (Burt; Vernon, 1950).

However, the results from the lower-class, black children do not fit this paradigm. The boys copied the angles and parallel lines more accurately than the girls did, and they drew the solid cube at a higher stage than the girls. The reason for these boys's superiority in cube drawing appears to be primarily graphic rather than conceptual. The evidence for this is that differences between boys and girls either in Children's Cubes Scale score or in accuracy of copying graphic elements accounted for their different cube drawing levels. On the basis of previous studies (such as Koppitz, 1964;

Koegh, 1968; and Haworth, 1970), sex differences in figure copying were not anticipated. However, as none of this previous work pertains specifically to a lower-class, black population, socioeconomic and racial factors might be expected to have some explanatory significance here.

It is further evident that (a) on the average, the black, lower-class males did not perform less well than the white, middle-class subjects, and (b) the sex differences in the black, lower-class sample are most pronounced in grades four through six. Thus, the sex differences are primarily due to a lower level of performance among the older black, lower-class, female subjects. Why this occurs is beyond the scope of the present study. Further research in this area would be necessary in order to clarify the relevant variables. Boys's and girls's cube drawing might be compared with their scores on performance IQ tests and on spatial tests such as Raven's Progressive Matrices. The racial factor might be pursued in the direction indicated by Bogen, Marsh, and TenHouten, who suggest that different cognitive modes may characterize black and white persons.

G. The Experimental Tasks and Children's Performance: An Interpretation

Taking the child at each stage of the cube drawing task, let us consider how he might experience the problems of cube drawing.

1. Drawing the Solid Cube: Stage 1

The youngest and least advanced subjects had very little competence with copying lines and angles, while slightly older subjects had begun to draw distinct right angles and acute angles. Both of these groups of children drew stage 1 cubes, with little of their grapho-motor progress reflected in their cube drawing. Further, although the majority of these children could identify the correct perspectival representation of a solid cube, they were satisfied

that they had drawn a "box" and they appeared indifferent to the failure of their own drawing to look like the picture of the cube which they had selected as best.

It will be recalled that some children who were considerably older, especially among the fourth graders, also drew stage 1 pictures of the solid cube. This seems the more remarkable in light of the fact that increases in elemental graphic skills and in scores on the Children's Cubes Scale were monotonic with respect to age. Indeed, from these abilities, one would have predicted that the older stage 1 children would be drawing stage 3 cubes instead. One explanation for this phenomenon is suggested by what the children said about their own responses, "It's too hard to do it that way [oblique projection], so I'll draw this [square] instead." Further, some of them pointed out that if one looked at a cube from a certain direction, then it did look like a square.

An additional procedure might be used to separate these two types of stage 1 children and to provide more information in general about children's ideas about the acceptability of cube drawings from the various stages. After they had selected the best picture of the solid cube, from the designs in Figure 5, children would be given various pairs of designs other than the square and the oblique projection and asked to select which of them was the better picture of the cube. For example, forms exemplary of stages 2 and 3 might be paired and a choice between them requested.

2. Copying a Line Drawing of a Cube: Stage 1

The occurrence of stage 1 among children's copies of a line drawing of a cube does not have the same significance as the stage 1 drawings of the solid cube. A stage 1 response rarely occurred for the copying task, and then only when the child also drew a square for the solid cube and for the task of drawing

that they had ...

their own ...

as best.

especially ...

other. ...

elements, ...

sometimes ...

predicted ...

instead. ...

said about ...

projection) ...

pointed out ...

look like ...

stage ...

these ...

they had ...

Figure 5, ...

square ...

better ...

might be ...

a picture of a "box." Earlier it was proposed that this was an instance of a drawing's being directed by the associative pull of an internal model.

Lurcat proposed a different explanation, namely, that the child reproduces only that part of the drawing which he knows how to draw. Following Lurcat's argument, it would be expected that the child would similarly simplify the two additional complex figures, shown in Figure 24,[1] by drawing only the square and omitting the two parallelograms. However, as none of the children in this study produced such a drawing, and Lurcat had no empirical basis for her explanation, her argument is unconvincing.

3. Stage 2 Drawings

Slightly older children have a stronger association between the solid cube and a correct perspectival representation of it. They know that a single square is not an adequate response. Their stage 2 productions might be explained in any of the following ways:

1. The child actually is depicting each face of the cube, but from multiple vantage points. He may actually ask to turn the cube so that he can draw each of the sides from the same position relative to himself; or he may in his imagination walk around the cube, successively drawing each face as though it were a head-on production. The transparent box and ball, as one third grader drew them (shown in Plate 3 in Appendix I), support this interpretation.
2. The child knows that each side ultimately is shaped like a square, although looking at a cube from different directions makes the sides take on sundry angular appearances. He symbolically represents that the cube has more than one side, and he draws what he knows the sides

[1]This experiment is presented in Appendix I.

look like rather than what he sees, possibly drawing as many as six squares.

3. The child is simplifying a complex figure by substituting right angles for more difficult angles. This phenomenon is not limited to cube drawing, because children also substitute right angles for acute and obtuse angles when they copy parallelograms and when they copy the two additional complex figures, in Figure 24.

The discrepancy among the three explanations of stage 2 cube forms may be understood by taking the former two explanations as describing children's drawing the solid cube, and the third as accounting for stage 2 drawings when a child is copying a two-dimensional projection of a cube. The evidence for attributing these different explanations to the different stimuli is as follows: Copying the two-dimensional projections at stage 3 rather than stages 1 and 2 is correlated with improved angle copying accuracy, suggesting that children who copy the two-dimensional projections at lower stages may do so so through lack of skill at reproducing the angular designs characteristic of higher stages. Thus, a stage 2 copy of an oblique or isometric projection may well result from the child's simplifying something too difficult for him to draw. Solid cubes continue to be drawn at stages 1 and 2, however, at a later age than the children's elemental graphic skills suggest that they could draw higher stage cubes, and after they have already begun copying the two-dimensional projections at higher stages. The transition from drawing stage 1 and 2 pictures of the solid cube (that is, drawings characterized by intellectual realism) to drawing stages 3, 4, and 5 (that is, visually realistic) pictures is related to the average strength of the association between the solid cube and a correct perspectival representation. The majority of children who draw stage 2 cubes seem to feel that their

representation is reasonable and adequate. The first two of our explanations for stage 2 cube drawings are two formulations of how this could come about.

4. Drawing Stage 3, 4, and 5 Cubes

Increased graphic ability correlates with progress from stage 3 to stage 5, for drawing a picture of the solid cube and for copying the two-dimensional projections. By stage 4, most children can copy a picture of a cube only slightly better than they can draw the solid. Probably this is because, when they are copying the oblique or isometric projection, the correct answer is available for reference. Many of the children trying to draw a solid cube would repeatedly draw a line, erase it, and redraw the same line, struggling to make their picture look like their image of a correct line drawing of a cube, but seemingly unable to direct their lines in order to accomplish it. Zaporozhets (1965) and Olson would argue that this is an instance of the different kinds and amounts of perceptual information necessary for carrying out different activities vis a vis an object:

> One requires different information to catch a ball (will it take one hand or two?) than to discriminate it from a cup, or to draw it, or to name it.[1]

Following this line of thought, the younger child selected enough perceptual cues to name a cube and to distinguish it from other geometrical configurations, but not enough to draw it. The older child has learned more properties, and the perspectival basis for the properties, of the conventional two-dimensional picture of a cube. As he draws a picture of the solid cube, he checks whether his drawing looks like what he sees when he looks at the solid cube or what he knows he is supposed to see.

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[1] D. R. Olson. Cognitive Development: The Child's Acquisition of Diagonality. New York: Academic Press, 1970. p. 185.

H. Conclusion

To review the major findings of this study with respect to the three original questions and the major points of the replication study:

1. What are the steps between perceiving and representing the object? A developmental sequence for cube drawing was empirically established, using two different methods--correlations of cube forms with age, and Guttman scaling of cube forms--and two different elementary school populations. Focussing on how children draw a single object has enabled more precise delineation of stages than was possible in more general studies of spatial representation hitherto. Extension of this work to include both older and younger children is an important direction which could be taken by future research. Secondly, the Children's Cubes Scale, as presently constituted, is a reliable instrument which better indicates the correlates of the different drawing stages. However, some particular weaknesses should be improved before the scale is applied to further research problems: (a) the twelfth item (see Table 6) was peculiarly difficult to scale and should probably be deleted; (b) there is a considerably larger gap between the ninth and tenth items than between any other two designs, and additional stage 3 figures should be devised and tested to see if any of them help to fill out the scale. Thereafter, the Children's Cubes Scale should have considerable utility as a diagnostic and research instrument in various additional populations, for example, among the mentally-retarded, the brain-damaged, or the aged.

2. In what order does a child acquire the specific perceptual-motor skills necessary for drawing complex geometric figures? A developmental sequence for acquisition of the ability to copy angles was established, and the relative difficulty of drawing parallel diagonal lines as compared to

parallel lines in a horizontal or vertical direction was demonstrated. This work might by itself be viewed as an interesting extension of Olson's study of diagonality. These same sequences were also reflected in the developmental sequence of cube forms. The particular selection of graphic elements for study was not intended to be exhaustive, however, and future research might focus on other elements relevant to cube drawing--reproduction of a line of a particular length, difficulty of angle copying as a function of orientation, copying three lines which meet at a single point--as well as other elemental graphic skills. Establishing these sorts of sequences would be expected to lead to increased understanding of copying difficulties in such standard figure copying tests as the Bender-Gestalt or the Graham-Kendall. This particular kind of developmental research has the advantage of quantitative and objective measurement.

3. How does acquisition of strategies for combining the specific perceptual-motor skills contribute to the ability to draw the object? The insufficiency of grapho-motoric development by itself to explain acquisition of the ability to draw a cube was demonstrated, and at the same time the precise role played by these developments in accounting for cube stages was shown. This effort goes beyond either Lurcat's cataloguing of cube copying difficulties or earlier descriptive studies of how children draw a variety of solid objects, in trying to study the influence of separate developments on the performance of a single task. Additional work along these lines might continue to take the cube as the exemplary task, focussing more closely on children's drawing strategies, and devising further experiments to elucidate the nature of children's conceptualizations underlying the early cube drawing stages. Although in this study children's drawing strategies were carefully observed, these data were not analyzed with respect to distinguishing

parallel lines in a ...
work might be ...
diagonality. The ...
sequence of cube ...
study was not ...
focus on ...
particular length ...
copying three ...
graphic skills ...
lead to increas...
figure copying ...
particular kind ...
and objective ...
2. The ...
perceptual-motor ...
insufficient...
of the ability ...
practice ...
shown. This ...
difficulties ...

characteristic drawing techniques. Such a procedure might help to illustrate changes in children's perception of the task. Both the colored cube and transparent box tasks, which were introduced in this study, are potentially useful devices for finding out more about what children at various stages are actually drawing pictures of.

Finally, the most valuable additional research would involve attempting to instruct children in cube drawing. For example, is there a level of conceptual readiness which must be achieved before stage 1 or 2 children will be responsive to instruction? What sorts of practice are most useful at each stage of development, and for the two- and three-dimensional drawing tasks? The colored cube was originally devised as an instructional tool, and it did seem to elicit some higher stage responses both spontaneously and in combination with verbal instruction. Its usefulness might be explored further. Cube completion exercises, used by Hecaen and Assal, and training in visual analysis, recommended by Zaporozhets, are other possible kinds of practice.

Taking as a problem how a child draws a cube, the present study has explored the difficulties which account for his performance and the developments which contribute to his success.

APPENDICES

APPENDIX A

EXPERIMENTAL PROTOCOL

Tasks:

A= oblique projection: copy it and name it
B= block problem: (a) match projective drawings to appropriate solids, (b) draw solid cube, (c) draw mock-cube
C= cube matching: pick best drawing of cube
D= copy isometric projection and additional complex figures
E= draw a "box"
M= picture matching: select objects which look like a cube
X= match angles to pictures of angles
Y= copy angles
Z= copy parallel lines
CCS= Children's Cubes Scale

Experimental sequences:

seq 1	seq 2	seq 3	seq 4	seq 5	seq 6	seq 7	seq 8
A	B	C	D	CCS	B	C	D
X	E	Z	X	A	Z	[illegible]	CCS
B	Y	A	C	Y	C	D	E
Y	D	Y	E	B	CCS	Y	Z
C	Z	D	CCS	E	X	B	A
Z	A	X	Z	X	A	CCS	Y
M	M	M	M	M	M	M	M
D	X	CCS	B	D	E	E	C
CCS	C	B	Y	Z	Y	Z	X
E	CCS	E	A	C	D	A	B

Orders of presentation of angles, for angle copying and angle matching:

0=1	0=2	0=3	0=4	0=5	0=6	0=7	0=8	0=9	0=10
15°	30°	45°	60°	75°	90°	105°	120°	135°	150°
60°	45°	30°	90°	105°	105°	150°	15°	45°	75°
120°	15°	15°	150°	45°	120°	75°	75°	75°	105°
105°	60°	135°	135°	150°	30°	60°	135°	30°	45°
150°	120°	75°	45°	15°	60°	45°	45°	15°	120°
30°	90°	150°	15°	30°	75°	90°	60°	90°	135°
90°	135°	90°	105°	60°	135°	120°	30°	150°	15°
135°	150°	120°	30°	120°	45°	135°	90°	120°	60°
45°	75°	60°	75°	90°	150°	15°	150°	60°	30°
75°	105°	105°	120°	135°	15°	30°	105°	105°	90°

APPENDIX B

ADDITIONAL DATA TABLES FOR EXPERIMENTS 1 AND 3, PEARSON SCHOOL

I. STAGE USAGE FOR DRAWING A PICTURE OF THE SOLID CUBE

II. STAGE USAGE FOR COPYING THE OBLIQUE PROJECTION OF THE CUBE

III. STAGE USAGE FOR COPYING THE ISOMETRIC PROJECTION OF THE CUBE

IV. STAGES FOR DRAWING THE MOCK-CUBE

V. COMPARISON OF STAGES FOR THE MOCK-CUBE DRAWING AND THE ACTUAL CUBE DRAWINGS

VI. CORRELATIONS OF CUBE TASKS WITH CHILDREN'S GRADE, AND INTERCORRELATIONS OF CUBE TASKS

VII. INTERCORRELATIONS OF SCORES ON DIFFERENT CUBE TASKS, WITHIN EACH GRADE, AND CORRELATION OF TASKS WITH IQ

TABLE I

STAGE USAGE FOR DRAWING A PICTURE OF THE SOLID CUBE, PEARSON SCHOOL

	Stage				
Grade	1	2	3	4	5
1 (N = 30)	.53	.27	.10	.10	.00
2 (N = 30)	.43	.40	.03	.13	.00
3 (N = 30)	.37	.17	.07	[illegible]	[illegible]
4 (N = 32)	.47	.19	.19	[illegible]	[illegible]
5 (N = 31)	.16	.13	.19	[illegible]	[illegible]
6 (N = 30)	.10	.13	.30	[illegible]	[illegible]
Total	.34	.21	.15	.26	.04

TABLE II

STAGE USAGE FOR COPYING THE OBLIQUE PROJECTION
OF THE CUBE, PEARSON SCHOOL

	Stage				
Grade	1	2	3	4	5
1 (N = 30)	.10	.27	.60	.03	.00
2 (N = 30)	.07	.27	.60	.03	.03
3 (N = 30)	.03	.17	.33	.40	[illegible]
4 (N = 32)	.16	.16	.37	.16	
5 (N = 31)	.00	.16	.23	.48	[illegible]
6 (N = 30)	.00	.03	.27	.50	.20
Total	.06	.17	.40	[illegible]	[illegible]

TABLE III

STAGE USAGE FOR COPYING THE ISOMETRIC PROJECTION OF THE CUBE, PEARSON SCHOOL

	Stage				
Grade	1	2	3	4	5
1 (N = 30)	.10	.10	.70	.10	.00
2 (N = 30)	.17	.23	.33	.27	[illegible]
3 (N = 30)	.03	.27	.40	.30	.00
4 (N = 32)	.12	.38	.19	[illegible]	[illegible]
5 (N = 31)	.00	.32	.39	.26	[illegible]
6 (N = 30)	.00	.10	.30	[illegible]	[illegible]
Total	.07	.24	.38	[illegible]	[illegible]

TABLE IV

STAGES FOR DRAWING THE MOCK-CUBE

Grade		Less Advanced	Stage 3	Stage 4	Stage 5
1	Frequency	18	4	6	2
	%	.600	.133	.200	.067
2	Frequency	12	8	9	1
	%	.400	.267	.300	.033
3	Frequency	13	4	9	4
	%	.433	.133	.300	.133
4	Frequency	9	3	12	8
	%	.282	.094	.375	.250
5	Frequency	5	2	16	8
	%	.161	.065	.516	.258
6	Frequency	2	3	15	10
	%	.067	.100	.500	.333
Total	Frequency	59	24	67	33
	%	.322	.131	.366	.180

TABLE V

COMPARISON OF STAGES FOR THE MOCK-CUBE DRAWING AND THE ACTUAL CUBE DRAWINGS

	Drawing the Mock-Cube Compared To		
	Drawing a Picture of a Solid Cube	Copying the Oblique Projection	Copying the Isometric Projection
% who drew the mock cube at a higher stage	.50	.38	.43
% who drew both at the same stage	.40	.36	.34
% who drew the mock cube at a lower stage	.10	.26	.23

TABLE VI

CORRELATIONS OF CUBE TASKS WITH CHILDREN'S GRADE, AND INTERCORRELATIONS OF CUBE TASKS

	Solid Cube	Oblique Projection	Isometric Projection	Mock-Cube	Cube Matching	Children's Cubes Scale	Mean Score	s.d.
A. With cubes scored according to the five hypothesized stages[a]								
Grade	.405	.418	.234	.459	.306	.660		
Solid Cube		.511	.367	.448	.221	.455	2.43	1.31
Oblique Projection			.587	.473	.069	.525	3.17	1.03
Isometric Projection				.350	-.029	.434	2.97	0.97
Mock-Cube					.148	.595	3.17	1.53
Cube Matching						.260	3.15	1.04
Children's Cubes Scale							8.51	3.47
B. With cubes scored according to substages[a]								
Grade	.407	.450	[illegible]	[illegible]	[illegible]	[illegible]		
Solid Cube		.510	.399	.424	.206	[illegible]	[illegible]	[illegible]
Oblique Projection			.605	.465	.075	[illegible]	[illegible]	[illegible]
Isometric Projection				.348	-.022	[illegible]	[illegible]	[illegible]
Mock-Cube					.151	.580	34.02	16.37
Cube Matching						[illegible]	3.15	1.04
Children's Cubes Scale							8.51	3.44

[a]For 183 subjects, a correlation of .146 is significant at the 5% level, and .189 is significant at the 1% level.

TABLE VI--Continued

	Solid Cube	Oblique Projection	Isometric Projection	Mock-Cube	Cube Matching	Children's Cubes Scale	Mean Score	s.d.
C. For male subjects only, with cubes scored by substage[b]								
Grade	.425	.490	.322	.487	.403	.631		
Solid Cube		.610	.445	.441	.226	.492	27.89	14.18
Oblique Projection			.659	.448	.159	.604	34.28	11.50
Isometric Projection				.347	.047	.530	33.06	11.26
Mock-Cube					.232	.592	37.17	15.53
Cube Matching						.272	3.20	1.06
Children's Cubes Scale							8.71	3.47
D. For female subjects only, with cubes scored by substage[c]								
Grade	.416	.416	.180	.464	.213	.697		
Solid Cube		.395	.335	.372	.173	[illegible]	[illegible]	[illegible]
Oblique Projection			.538	.483	-.024	[illegible]	[illegible]	[illegible]
Isometric Projection				.335	-.108	.340	[illegible]	[illegible]
Mock-Cube					.062	.572	30.97	[illegible]
Cube Matching						.243	3.10	1.01
Children's Cubes Scale							8.32	3.41

[b] For 90 subjects, a correlation of .207 is significant at the 5% level, and .270 is significant at the 1% level.

[c] For 93 subjects, a correlation of .203 is significant at the 5% level, and .265 is significant at the 1% level.

VII. INTERCORRELATIONS OF SCORES ON DIFFERENT CUBE TASKS, WITHIN EACH GRADE, AND CORRELATION OF TASKS WITH IQ

A. for all subjects, with cubes scored by substage

FIRST GRADE (N=30)	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-0794	-0115	0774	2119	3379	3409	93.33333333	16.49417991
SOLID		3156	4952*	1532	2093	1441	18.75000000	11.44457342
OBL			7639*	0073	1669	1008	26.25000000	7.97414299
ISO				2021	1039	3672*	28.95833333	8.96601878
MOCK					1241	5688*	20.00000000	18.59172326
MATCH						2832	2.25000000	1.22474487
CCS							4.58333333	2.56932856

SECOND GRADE (N=30)	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-1051	3066	3210	0202	-1779	-3008	92.07142857	13.15978321
SOLID		2716	0924	3605*	-1782	-1076	18.75000000	10.50793351
OBL			6619*	6322*	-4098*	3012	27.85714285	8.75897121
ISO				4940*	-3150	5040*	28.57142857	12.38705588
MOCK					-1985	4858*	27.67857142	17.29280212
MATCH						1776	3.00000000	1.18634202
CCS							5.96428571	2.98740743

THIRD GRADE (N=30)	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-0500	2330	-0476	-1220	1665	1454	95.39285714	15.25666651
SOLID		3200	2416	4078*	0690	1617	25.89285714	13.81448323
OBL			4178*	4011*	0264	3092	35.53571428	9.93863446
ISO				-1824	-1365	0117	31.60714285	9.81812113
MOCK					0744	2849	31.42857142	13.73405761
MATCH						-0504	3.21428571	0.95673607
CCS							8.71428571	2.52186208

FOURTH GRADE (N=32)	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	1121	1566	2404	5655*	0535	3931*	92.18518518	11.84527506
SOLID		4856*	4100*	2165	0668	2555	21.29629629	11.97694842
OBL			6376*	3245	-1822	6503*	34.25925926	11.57780566
ISO				1842	-4981*	5983*	30.92592592	11.68801465
MOCK					-0164	4527*	36.29629629	16.38436124
MATCH						-2140	3.03703703	0.89792416
CCS							9.33333333	2.86893172

FIFTH GRADE (N=31)	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	1952	2631	1753	-0780	-1649	1868	102.4444	10.65303616
SOLID		2479	4931*	2643	2394	4729*	34.25925926	14.12197576
OBL			3115	4016*	1251	2743	39.62962963	8.97924165
ISO				4747*	2453	6494*	33.88888888	9.12870929
MOCK					1145	4391*	41.48148148	12.15404450
MATCH						1163	3.48148148	0.84899806
CCS							11.14814814	1.97491389

SIXTH GRADE (N=30)	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	2623	1177	2961	0281	-0881	3734*	94.29629629	10.94326211
SOLID		3731*	2633	3094	2074	4157*	34.40740740	11.03581323
OBL			5518*	2936	-1132	0588	41.29629629	7.15119578
ISO				2051	-0546	2662	38.70370370	8.72580088
MOCK					-0899	2007	43.70370370	8.15623789
MATCH						-1059	3.59259259	0.74726471
CCS							10.81481481	1.96188757

FIRST GRADE BOYS (N=18)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-3404	-3682	-1690	5674*	1913	2492	92.46666666	16.50050504
SOLID		3253	5087*	0914	2535	0208	20.66666666	11.62919151
OBL			6905*	-1381	0870	-2234	27.66666666	7.03731550
ISO				2061	0293	2576	30.00000000	8.45154254
MOCK					3801	7392*	26.00000000	10.47525903
MATCH						2693	2.06666666	1.43759057
CCS							5.00000000	2.95109690

SECOND GRADE BOYS (N=11)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-5569	-7192*	-6989*	-8068*	3968	-5204	84.90000000	9.06090503
SOLID		5499	2935	6706*	-4334	2630	22.00000000	12.06464071
OBL			3952	8858*	-5472	3953	24.50000000	8.95978670
ISO				5464	-3432	7749*	25.00000000	13.33333333
MOCK					-5836	3871	31.00000000	17.91957340
MATCH						-6513*	3.50000000	0.84983658
CCS							6.20000000	3.01109061

THIRD GRADE BOYS (N=15)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-0001	2743	3469	-3744	0811	1641	97.84615384	15.77892135
SOLID		4951	3981	6663*	-1714	3506	27.30769230	14.94648573
OBL			6646*	3283	-1216	5255*	34.23076923	11.51921471
ISO				0710	2453	4201	31.92307692	11.09400392
MOCK					-3306	0396	29.23076923	15.25425539
MATCH						0492	3.[illegible]53846[illegible]	0.80064076
CCS							[illegible]	1.599[illegible]0957

FOURTH GRADE BOYS (N=20)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	0232	0087	1302	4020	-1009	4981*	94.2[illegible]9411	10.991[illegible]
SOLID		4403*	2200	-0087	4095	0809	22.35294117	12.3892[illegible]
OBL			6334*	1585	-1139	6505*	35.29411764	12.17972036
ISO				-0607	-5628*	5174*	32.05882353	11.8662893[illegible]
MOCK					2073	4505*	41.764705[illegible]	11.85073801
MATCH						-0972	3.[illegible]	0.927[illegible]
CCS							[illegible]	2.895[illegible]

FIFTH GRADE BOYS (N=12)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	2195	4785	7390*	1607	0619	5065	10[illegible].7000	9.63846460
SOLID		5892*	-0889	-1266	-1329	2973	40.50000000	11.89070599
OBL			-0060	2516	5576	0843	[illegible].50000000	5.98609499
ISO				0564	-2536	4198	39.50000000	7.61941963
MOCK					2721	3912	47.00000000	2.58198889
MATCH						-1064	3.80000000	0.63245553
CCS							12.50000000	1.64991582

SIXTH GRADE BOYS (N=14)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	2672	-1656	3557	0174	-0728	3040	93.46153846	12.03200859
SOLID		4739	3688	4137	-1617	6465*	37.30769230	9.49021088
OBL			3665	5544*	5514*	1213	43.07692307	6.62648145
ISO				1387	5059	3215	40.76923077	8.37808496
MOCK					-0170	4070	46.53846153	4.27425207
MATCH						-1791	3.76923077	0.43852901
CCS							10.46153846	1.71344607

FIRST GRADE GIRLS (N=12)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS	STANDARD DEVIATION
IQ	4150	4759	4512	-4092	8625*	7519*	93.77777777	17.37[illegible]
SOLID		2206	4394	0[illegible]0	3468	3723	15.55555555	11.0[illegible]16379
OBL			8352*	-0549	6592*	7078*	23.833[illegible]38	9.[illegible]7360727
ISO				0598	4953	6823*	27.22222222	10.0[illegible]66211
MOCK					-5619	-4223	10.00000000	12.24[illegible]871
MATCH						7685*	2.55555555	0.72643315
CCS							3.83333333	1.69143192

SECOND GRADE GIRLS (N=19)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS	STANDARD DEVIATION
IQ	2332	5769*	6543*	4221	-1537	2172	96.05555555	13.5[illegible]
SOLID		2328	0428	1076	-2219	-3879	15.94444444	9.41528315
OBL			8004*	6099*	-2354	2994	29.72222222	8.30378733
ISO				5445*	-2445	3882	30.55555555	11.74344434
MOCK					-1500	5357*	25.33333333	17.17128245
MATCH						4560*	2.72222222	1.27443438
CCS							5.83333333	3.05344549

THIRD GRADE GIRLS (N=15)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS	STANDARD DEVIATION
IQ	-1334	2491	-4998	1988	2464	1709	93.26666666	15.00222205
SOLID		1316	0494	1485	2534	0000	24.66666666	13.15656634
OBL			0850	4771	1385	0331	36.66666666	8.59124693
ISO				-5955	-4374	-4293	31.33333333	8.95757195
MOCK					3727	5247*	33.33333333	12.48803956
MATCH						-1295	3.26666666	1.09973352
CCS							9.00000000	2.59713268

FOURTH GRADE GIRLS (N=12)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS	STANDARD DEVIATION
IQ	1931	3479	3544	6637*	2312	2037	88.70000000	13.00470000
SOLID		5593*	7472*	4243	-6587*	5528	19.50000000	11.65475582
OBL			6316*	5160	-3795	6384*	32.50000000	10.86533734
ISO				3772	-4432	7253*	29.00000000	11.73787799
MOCK					-4137	4760	27.00000000	19.32183566
MATCH						-4818	2.90000000	0.87559503
CCS							8.90000000	2.92308817

FIFTH GRADE GIRLS (N=19)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS	STANDARD DEVIATION
IQ	2320	2702	0136	-0886	-2275	1439	102.8323	11.47215298
SOLID		-0198	6022*	2025	2465	3939	30.58823529	14.34860168
OBL			1837	3158	-1369	0557	36.76470588	9.34431252
ISO				4467	2576	5830*	30.58823529	8.45620204
MOCK					-0055	3538	33.23529411	14.35500527
MATCH						-0300	3.29411764	0.91955871
CCS							10.35294117	1.72992689

SIXTH GRADE GIRLS (N=16)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS	STANDARD DEVIATION
IQ	3247	4391	2942	0854	-0836	4345	95.07142857	10.22413649
SOLID		2392	1130	2906	2713	3926	31.71428571	12.00915401
OBL			6474*	1339	-4714	0980	39.64285714	7.45867737
ISO				1491	-3751	3229	36.78571428	8.90270979
MOCK					-2160	2563	41.07142857	10.03428189
MATCH						-0322	3.42857142	0.93761446
CCS							11.14285714	2.17881911

MATCH = CUBE AND BLOCK MATCHING
CCS = CHILDREN'S CUBES SCALE

APPENDIX C

SUMMARY TABLES FOR THE ANALYSES OF VARIANCE IN EXPERIMENTS 1 AND 3, PEARSON SCHOOL

I. ANALYSIS OF VARIANCE OF CUBE STAGES, COMPARING ORDERS OF PRESENTATION

II. ANALYSIS OF VARIANCE OF CUBE STAGES, ACCORDING TO GRADE AND SEX OF THE SUBJECT

III. ANALYSIS OF VARIANCE, COVARYING THE EFFECTS OF IQ ON CUBE DRAWING STAGE

IV. ANALYSIS OF VARIANCE OF CUBE AND BLOCK MATCHING, ACCORDING TO GRADE AND SEX OF THE SUBJECT

V. ANALYSIS OF VARIANCE OF CHILDREN'S CUBES SCALE SCORES, ACCORDING TO GRADE AND SEX OF THE SUBJECT

VI. ANALYSIS OF VARIANCE OF STAGES OF DRAWING THE MOCK-CUBE, ACCORDING TO GRADE AND SEX OF THE SUBJECT

VII. ANALYSIS OF VARIANCE OF CUBE AND MOCK-CUBE STAGES, COVARYING THE CHILDREN'S CUBES SCALE SCORE

TABLE I

ANALYSIS OF VARIANCE OF CUBE STAGES,
COMPARING ORDERS OF PRESENTATION

A. Drawing a Picture of a Solid Cube

Grade		Mean Stage of Drawing: When the Solid Cube was the First Cube Stimulus	When the Solid Cube was Drawn after One Other Cube Drawing Task	When the Solid Cube was the Last Cube Drawing Task
1	mean	23.00	12.00	21.33
	s.d	18.23	4.22	12.17
2	mean	24.38	20.38	13.89
	s.d.	12.37	11.45	6.01
3	mean	21.25	26.88	37.50
	s.d.	13.72	15.10	6.12
4	mean	20.00	18.21	28.57
	s.d.	8.94	13.24	14.92
5	mean	27.50	31.11	40.00
	s.d.	16.04	11.67	11.44
6	mean	32.86	38.25	30.00
	s.d.	12.86	8.11	13.04

Analysis of Variance

Source of Variation	DF	Mean Square	F
Order	2	280.24	1.97
Grade	5	1213.90	8.51**
Grade x order	10	348.83	2.45**
Error	165	142.60	

** indicates 1% level of significance; * indicates 5% level.

TABLE I--Continued

B. Copying the Oblique Projection

Mean Stage of Drawing

Grade		When the Oblique Projection was the First Cube Stimulus	When the Oblique Projection was Copied after One Other Cube Drawing Task	When Copying the Oblique Projection was the Last Cube Drawing Task
1	mean	25.79	30.00	28.00
	s.d.	8.70	0.0	8.23
2	mean	29.69	20.00	26.15
	s.d.	6.18	0.0	10.64
3	mean	34.28	28.33	37.50
	s.d.	7.32	5.77	10.94
4	mean	30.00	32.50	33.85
	s.d.	12.96	10.41	14.74
5	mean	38.33	43.00	36.82
	s.d.	9.94	4.47	11.24
6	mean	40.31	40.83	43.75
	s.d.	6.45	5.85	8.35

Analysis of Variance

Source of Variation	DF	Mean Square	F
Order	2	25.83	0.27
Grade	5	533.25	5.76**
Grade x order	10	56.97	0.59
Error	165	96.11	

** indicates 1% level of significance; * indicates 5% level.

TABLE I--Continued

C. Copying the Isometric Projection

Mean Stage of Drawing

Grade		When the Isometric Projection was the First Cube Stimulus	When the Isometric Projection was Copied After One Other Cube Drawing Task	When Copying the Isometric Projection was the Last Cube Drawing Task
1	mean	30.00	31.05	29.00
	s.d.	5.48	9.37	12.45
2	mean	31.67	30.31	24.38
	s.d.	15.70	10.72	13.21
3	mean	35.00	32.37	22.50
	s.d.	7.07	10.05	5.00
4	mean	32.50	29.28	28.75
	s.d.	9.35	12.67	13.84
5	mean	32.50	32.65	35.00
	s.d.	11.65	9.37	6.32
6	mean	37.14	40.83	39.54
	s.d.	8.59	9.00	8.79

Analysis of Variance

Source of Variation	DF	Mean Square	F
Order	2	156.55	1.43
Grade	5	367.32	3.36**
Grade x order	10	81.38	0.75
Error	165	109.22	

** indicates 1% level of significance; * indicates 5% level.

TABLE II

ANALYSIS OF VARIANCE OF CUBE STAGES, ACCORDING TO GRADE AND SEX OF THE SUBJECT

Source of Variation	DF	Mean Square	F
A. Drawing a Picture of a Solid Cube			
Sex	1	1590.43	10.56**
Grade	5	1696.03	11.26**
Grade x sex	5	62.52	0.41
Error	171	150.58	
B. Copying the Oblique Projection			
Sex	1	145.96	1.58
Grade	5	1165.44	12.64**
Grade x sex	5	137.14	1.49
Error	171	92.23	
C. Copying the Isometric Projection			
Sex	1	165.17	1.58
Grade	5	510.46	4.88**
Grade x sex	5	161.03	1.54
Error	171	104.63	

** indicates 1% level of significance; * indicates 5% level.

TABLE III

ANALYSIS OF VARIANCE, COVARYING THE EFFECTS
OF IQ ON CUBE DRAWING STAGE

Source of Variation	DF	Mean Square	F	Significance Level
A. For drawing a picture of the solid cube				
Regression of IQ on stage	1	180.76	1.393	.240
Grade	5	1453.49	11.200	.001
Sex	1	1031.06	12.102	.001
Grade x sex	5	60.36	.465	.802
Error	122	129.77		
B. For copying the oblique projection				
Regression of IQ on stage	1	419.79	4.917	.028
Grade	5	966.04	11.315	.001
Sex	1	85.70	1.004	.318
Grade x sex	5	113.82	1.333	.255
Error	122	85.38		
C. For copying the isometric projection				
Regression of IQ on stage	1	45.27	.418	.519
Grade	5	436.90	4.035	.002
Sex	1	135.82	1.254	.265
Grade x sex	5	150.95	1.394	.231
Error	122	108.271		

TABLE IV

ANALYSIS OF VARIANCE OF CUBE AND BLOCK MATCHING, ACCORDING TO GRADE AND SEX OF THE SUBJECT

Source of Variation	DF	Mean Square	F
Sex	1	1.56	1.62
Grade	5	4.23	4.39**
Grade x sex	5	1.32	1.37
Error	171	.96	

TABLE V

ANALYSIS OF VARIANCE OF CHILDREN'S CUBES SCALE SCORES, ACCORDING TO GRADE AND SEX OF THE SUBJECT

Source of Variation	DF	Mean Square	F
Sex	1	16.77	2.66
Grade	5	206.62	32.75**
Grade x sex	5	10.31	1.63
Error	171	6.31	

** indicates 1% level of significance; * indicates 5% level.

TABLE VI

ANALYSIS OF VARIANCE OF STAGES OF DRAWING THE MOCK-CUBE, ACCORDING TO GRADE AND SEX OF THE SUBJECT

A. Mean Scores

Grade		Boys	Girls	Average
	no. of subjects	18	12	
1	mean	27.50	13.33	21.83
	s.d.	19.50	14.82	18.87
	no. of subjects	11	19	
2	mean	30.00	26.84	28.00
	s.d.	17.32	17.26	17.05
	no. of subjects	15	15	
3	mean	31.67	33.33	32.50
	s.d.	15.54	12.49	13.88
	no. of subjects	20	12	
4	mean	41.25	28.33	36.41
	s.d.	12.12	18.87	16.03
	no of subjects	12	19	
5	mean	47.08	37.10	40.97
	s.d.	2.57	14.17	12.14
	no. of subjects	14	16	
6	mean	46.78	41.56	44.00
	s.d.	4.21	9.44	7.81

B. Analysis of Variance

Source of Variation	DF	Mean Square	F
Sex	1	2339.86	11.51**
Grade	5	2268.81	11.16**
Grade x sex	5	275.08	1.35
Error	171	203.34	

** indicates 1% level of significance; * indicates 5% level.

TABLE VII

ANALYSIS OF VARIANCE OF CUBE AND MOCK-CUBE STAGES, COVARYING THE CHILDREN'S CUBES SCALE SCORE

Source of Variance	DF	Mean Square	F	Significance Level
Mock-Cube				
Within cells	170	171.61		
Regression of Children's Cubes Scale	1	5598.42	32.62	.001
Grade	5	160.68	.936	.459
Sex	1	1234.29	7.192	.008
Grade x sex	5	185.66	1.082	.372
Solid Cube				
Within cells	176	147.335		
Regression of Children's Cubes Scale	1	1724.576	11.705	.001
Grade	5	530.095	3.598	.004
Oblique Projection				
Within cells	176	82.66		
Regression of Children's Cubes Scale	1	2050.49	24.806	.001
Grade	5	205.466	2.486	.033
Isometric Projection				
Within cells	176	87.35		
Regression of Children's Cubes Scale	1	3479.39	39.834	.001
Grade	5	322.15	3.688	.003

APPENDIX D

ADDITIONAL DATA TABLES FOR EXPERIMENT 2, PEARSON SCHOOL

I. FREQUENCY WITH WHICH A SUBJECT REPEATEDLY DREW AN ANGLE OF THE SAME SIZE

II. FREQUENCY OF OCCURRENCE OF ANGLE-COPYING ABERRATIONS

III. ANGLE MATCHING DATA

IV. FREQUENCY WITH WHICH DIFFERENT ANGLES WERE SELECTED AS MATCHES

V. PARALLEL LINES DATA

TABLE I

FREQUENCY WITH WHICH A SUBJECT REPEATEDLY DREW AN ANGLE OF THE SAME SIZE

Grade	Number of Times the Same Size Angle Occurred		Number of Times the Same Size Vertex Occurred	
	3 Times or More	4 or More Times	3 Times or More	4 or More Times
1 (N = 30)	20	5	25	6
2 (N = 30)	27	7	27	9
3 (N = 30)	25	9	29	2
4 (N = 32)	13	1	19	2
5 (N = 31)	15	1	18	5
6 (N = 30)	18	2	17	2

TABLE II

FREQUENCY OF OCCURRENCE OF ANGLE-COPYING ABERRATIONS[a]

Grade	Bow	Skew	Fan	Double Vertex	Inverted Vertex	Gap	Bend	Oriented Upward	Oriented Downward and/or to the Left
1 (N=300)[b]	32	107	45	5	3	9	5	29	8
2 (N=300)	21	56	65	0	2	3	5	26	2
3 (N=300)	5	50	45	2	1	1	0	18	4
4 (N=320)	13	74	36	3	2	1	2	14	3
5 (N=310)	2	43	30	2	2	0	2	10	0
6 (N=300)	14	80	23	1	3	1	1	9	0

[a]Refer to Figure 12 for illustrations.

[b]Each subject drew ten angles.

TABLE III

ANGLE MATCHING DATA

A. Average size of angles chosen

Angle		Grade 1	2	3	4	5	6	Average
15°	av. size of angle chosen	19.00	18.50	15.50	16.88	14.50	15.48	16.64
	s.d. of angle size	7.81	6.45	2.74	5.04	2.74	2.69	5.19
30°	av. size of angle chosen	28.50	28.00	36.00	33.28	29.50	30.00	30.90
	s.d. of angle size	8.22	9.43	21.07	9.89	7.35	3.87	11.47
45°	av. size of angle chosen	32.50	36.50	37.00	39.84	39.50	39.68	37.54
	s.d. of angle size	15.80	8.52	9.43	8.18	10.78	7.30	10.53
60°	av. size of angle chosen	52.50	53.00	51.50	50.62	49.50	54.68	51.97
	s.d. of angle size	17.06	17.05	12.26	13.60	14.82	9.12	14.13
75°	av. size of angle chosen	76.00	71.00	75.00	78.28	70.50	69.19	73.36
	s.d. of angle size	22.61	18.45	21.21	14.62	21.63	10.01	18.60
90°	av. size of angle chosen	84.50	89.50	88.00	90.94	87.00	89.03	88.20
	s.d. of angle size	14.99	8.34	12.90	8.47	17.35	3.75	11.84
105°	av. size of angle chosen	106.50	112.00	107.50	107.34	104.50	106.45	107.38
	s.d. of angle size	18.20	19.19	15.30	14.81	22.10	13.05	17.24

TABLE III --Continued

Angle		Grade 1	2	3	4	5	6	Average
120°	av. size of angle chosen	118.00	113.00	116.00	117.66	114.00	117.07	115.98
	s.d. of angle size	10.95	26.64	14.17	10.16	26.89	11.89	17.99
135°	av. size of angle chosen	136.50	134.00	142.00	135.94	125.00	136.94	135.08
	s.d. of angle size	14.39	17.59	9.43	16.58	33.50	9.28	19.03
150°	av. size of angle chosen	138.00	145.00	144.50	145.31	142.50	149.52	144.18
	s.d. of angle size	19.85	8.20	7.35	8.03	27.50	2.69	15.06

B. Angles arranged in order, according to how well each one was matched

Most often matched correctly	15°
	30°
	90°
	150°
	45°
	120°
	135°
	105°
	75°
Least often matched correctly	60°

TABLE IV

FREQUENCY WITH WHICH DIFFERENT ANGLES
WERE SELECTED AS MATCHES

A. Average number of times the angle was selected

Grade	15	30	45	60	75	90	105	120	135	150
1	1.33	1.27	1.17	.43	1.00	.77	1.07	1.07	.90	1.00
2	1.07	1.50	1.13	.77	.73	.87	.83	.93	1.00	1.17
3	1.03	1.47	1.07	.70	.83	.80	.90	1.00	1.03	1.17
4	.94	1.41	1.12	.62	.91	.91	.97	1.12	.97	1.03
5	1.03	1.26	1.26	.65	.68	.94	1.03	.90	.97	.97
6	1.00	1.33	1.13	.83	.83	.97	.87	1.00	.80	1.23

B. Angles arranged in order according to the frequency
with which each one was selected as a match

Most frequently picked	30°
	45°
	150°
	15°
	120°
	105°
	135°
	90°
	75°
Least frequently picked	60°

TABLE V

PARALLEL LINES DATA

		Grade						
	Line Direction	1	2	3	4	5	6	Average
Horizontal	av. accuracy of orientation	7.77	6.10	5.57	5.88	5.00	3.03	5.56
	s.d. of orientation accuracy	6.83	4.33	4.57	7.90	4.08	2.24	5.47
	av. angular separation	3.97	3.43	2.53	2.38	2.19	1.57	2.67
	s.d. of angular separation	3.61	2.74	1.91	1.81	1.60	1.65	2.38
Vertical	av. accuracy of orientation	7.63	10.10	10.87	7.97	5.58	4.37	7.74
	s.d. of orientation accuracy	6.74	9.55	12.00	6.70	3.92	3.22	7.86
	av. angular separation	4.40	4.50	4.63	3.38	2.55	1.73	3.52
	s.d. of angular separation	4.01	3.63	4.39	3.31	2.29	1.48	3.46
Diagonal	av. accuracy of orientation	14.07	12.17	9.80	8.56	10.84	7.83	10.52
	s.d. of orientation accuracy	10.83	9.29	7.01	6.94	7.94	6.38	8.36
	av. angular separation	6.90	6.80	4.63	4.09	3.35	3.57	4.87
	s.d. of angular separation	5.97	4.98	3.56	4.28	2.61	2.62	4.37
Average	av. accuracy of orientation	9.82	9.46	8.74	7.47	7.14	5.08	7.94
	s.d. of orientation accuracy	8.80	8.39	8.67	7.22	6.16	4.73	7.60
	av. angular separation	5.09	4.91	3.93	3.28	2.70	2.29	3.69
	s.d. of angular separation	4.78	4.10	3.55	3.33	2.24	2.06	3.61

APPENDIX E

SUMMARY TABLES FOR THE ANALYSES OF VARIANCE IN EXPERIMENT 2, PEARSON SCHOOL

I. GRADE AND ORDER EFFECTS FOR COPYING ANGLES

II. GRADE AND SEX EFFECTS FOR COPYING ANGLES

III. GRADE AND ORDER EFFECTS FOR MATCHING ANGLES

IV. GRADE AND SEX EFFECTS FOR MATCHING ANGLES

V. GRADE EFFECTS FOR COPYING ANGLES, WITH ANGLE MATCHING COVARIED

VI. GRADE AND ORDER EFFECTS FOR COPYING PARALLEL LINES

VII. GRADE AND SEX EFFECTS FOR COPYING PARALLEL LINES

VIII. GRADE AND SEX EFFECTS FOR ALL FIVE TRANSFORMED COPYING VARIABLES, COVARYING IQ

IX. SUMMARY TABLES FOR ANALYSES IN WHICH THE FIVE TRANSFORMED COPYING VARIABLES ARE COVARIED

X. SUMMARY TABLES FOR ANALYSES COMPARING THE STAGES OF DRAWING THE DIFFERENT CUBE STIMULI

XI. ANALYSES USING DRAWING STAGE AS THE INDEPENDENT VARIABLE

I. GRADE AND ORDER EFFECTS FOR COPYING ANGLES

TEST OF GRADE X ORDER

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.035	180.000	481.417	0.382	0.608
2 THROUGH 4	0.900	132.000	503.351	0.767	0.541
3 THROUGH 4	0.811	86.000	524.280	0.885	0.488
4 THROUGH 4	0.758	42.000	544.203	0.867	0.450

VARIABLE	UNIVARIATE F TESTS F(45, 123)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RIGHT VS. ACUTE	0.870	30.824	0.698	0.520
AC-ACUTE VS. OBTUSE	1.091	118.668	0.347	0.018
AC-ACUTE	1.020	28.949	0.452	-0.733
AC-OBTUSE	1.083	96.165	0.358	-0.753

TEST OF GRADE

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.718	20.000	398.945	0.028 *	0.429
2 THROUGH 4	0.715	12.000	369.244	0.737	0.199
3 THROUGH 4	0.606	6.000	320.781	0.725	0.126
4 THROUGH 4	0.837	2.000	243.080	0.434	0.117

VARIABLE	UNIVARIATE F TESTS F(5, 123)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RIGHT VS. ACUTE	1.241	43.938	0.294	0.274
AC-ACUTE VS. OBTUSE	3.827	416.138	0.003	0.887
AC-ACUTE	1.494	42.394	0.196	0.444
AC-OBTUSE	1.179	104.655	0.323	-0.198

DISCRIMINANT SCORES

CONTRAST	1
1	0.104
2	0.650
3	0.294
4	-0.256
5	-0.243

TEST OF ORDER

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.189	36.000	451.433	0.214	0.412
2 THROUGH 4	0.792	24.000	448.133	0.748	0.288
3 THROUGH 4	0.586	14.000	441.088	0.877	0.230
4 THROUGH 4	0.244	6.000	428.840	0.962	0.109

VARIABLE	UNIVARIATE F TESTS F(9, 123)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RIGHT VS. ACUTE	1.325	46.939	0.231	0.601
AC-ACUTE VS. OBTUSE	1.375	149.460	0.207	-0.452
AC-ACUTE	1.084	30.759	0.379	-0.717
AC-OBTUSE	0.901	80.034	0.527	-0.407

II. GRADE AND SEX EFFECTS FOR COPYING ANGLES

TEST OF GRADE X SEX

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.289	20.000	558.143	0.179	0.262
2 THROUGH 4	1.117	12.000	515.886	0.343	0.213
3 THROUGH 4	0.906	6.000	447.778	0.490	0.163
4 THROUGH 4	0.433	2.000	339.000	0.649	0.071

VARIABLE	UNIVARIATE F TESTS F(5, 171)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RIGHT VS. ACUTE	1.351	46.614	0.245	0.419
AC-ACUTE VS. OBTUSE	0.569	60.309	0.724	0.393
AC-ACUTE	1.845	51.580	0.107	-0.674
AC-OBTUSE	0.984	88.490	0.429	-0.750

TEST OF GRADE

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.737	20.000	558.143	0.025*	0.373
2 THROUGH 4	0.720	12.000	515.886	0.732	0.174
3 THROUGH 4	0.570	6.000	447.778	0.754	0.105
4 THROUGH 4	0.761	2.000	339.000	0.468	0.094

VARIABLE	UNIVARIATE F TESTS F(5, 171)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RIGHT VS. ACUTE	1.339	46.210	0.250	0.378
AC-ACUTE VS. OBTUSE	3.719	394.085	0.003	0.870
AC-ACUTE	1.455	40.689	0.207	0.413
AC-OBTUSE	1.254	112.761	0.286	-0.216

DISCRIMINANT SCORES

CONTRAST	I
1	0.165
2	0.618
3	0.264
4	-0.130
5	-0.385

TEST OF SEX

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	4.220	4.000	168.000	0.003**	0.302

VARIABLE	UNIVARIATE F TESTS F(1, 171)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RIGHT VS. ACUTE	0.904	31.213	0.343	0.175
AC-ACUTE VS. OBTUSE	15.424	1634.646	0.001	0.994
AC-ACUTE	1.087	30.393	0.298	0.237
AC-OBTUSE	1.597	143.668	0.208	-0.135

DISCRIMINANT SCORES

CONTRAST	I
1	-0.312

III. GRADE AND ORDER EFFECTS FOR MATCHING ANGLES

TEST OF GRADE X ORDER

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.321	180.000	481.417	0.010*	0.672
2 THROUGH 4	1.086	132.000	503.351	0.264	0.602
3 THROUGH 4	0.900	86.000	524.280	0.723	0.549
4 THROUGH 4	0.633	42.000	544.203	0.966	0.416

VARIABLE	UNIVARIATE F TESTS F(45, 123)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AM-RIGHT VS. ACUTE	0.998	106.647	0.488	0.085
AM-ACUTE VS. OBTUSE	2.150	17.659	0.001	0.974
AM-ACUTE	0.832	0.674	0.756	0.117
AM-OBTUSE	1.452	0.607	0.056	-0.354

TEST OF GRADE

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	2.961	20.000	398.945	0.001**	0.556
2 THROUGH 4	0.907	12.000	369.244	0.540	0.277
3 THROUGH 4	0.181	6.000	320.781	0.982	0.092
4 THROUGH 4	0.021	2.000	243.000	0.980	0.018

VARIABLE	UNIVARIATE F TESTS F(5, 123)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AM-RIGHT VS. ACUTE	2.242	239.639	0.054	0.210
AM-ACUTE VS. OBTUSE	5.487	45.071	0.001	0.780
AM-ACUTE	0.426	0.345	0.830	0.269
AM-OBTUSE	3.512	1.468	0.005	-0.677

DISCRIMINANT SCORES

CONTRAST	1
1	0.810
2	0.660
3	-0.262
4	-0.164
5	-0.729

TEST OF ORDER

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	1.233	36.000	451.433	0.171	0.393
2 THROUGH 4	0.951	24.000	448.133	0.531	0.340
3 THROUGH 4	0.529	14.000	441.088	0.916	0.224
4 THROUGH 4	0.180	6.000	428.840	0.982	0.094

VARIABLE	UNIVARIATE F TESTS F(9, 123)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AM-RIGHT VS. ACUTE	2.075	221.716	0.037	0.728
AM-ACUTE VS. OBTUSE	2.034	16.706	0.041	-0.697
AM-ACUTE	0.664	0.538	0.740	-0.169
AM-OBTUSE	0.254	0.106	0.985	-0.069

IV. GRADE AND SEX EFFECTS FOR MATCHING ANGLES

TEST OF GRADE X SEX

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DF HYP	DF ERR	P LESS THAN	R
1 THROUGH 4	0.473	20.000	558.143	0.976	0.187
2 THROUGH 4	0.282	12.000	515.886	0.992	0.120
3 THROUGH 4	0.153	6.000	447.778	0.988	0.071
4 THROUGH 4	0.026	2.000	339.000	0.975	0.017

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(5, 171)	MEAN SQ	P LESS THAN	1
AM-RIGHT VS. ACUTE	0.324	37.217	0.898	0.201
AM-ACUTE VS. OBTUSE	0.243	2.745	0.943	0.278
AM-ACUTE	0.827	0.628	0.532	0.851
AM-OBTUSE	0.399	0.183	0.849	-0.535

TEST OF GRADE

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DF HYP	DF ERR	P LESS THAN	R
1 THROUGH 4	2.425	20.000	558.143	0.001**	0.444
2 THROUGH 4	0.801	12.000	515.886	0.649	0.219
3 THROUGH 4	0.204	6.000	447.778	0.975	0.083
4 THROUGH 4	0.021	2.000	339.000	0.979	0.016

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(5, 171)	MEAN SQ	P LESS THAN	1
AM-RIGHT VS. ACUTE	1.967	225.910	0.086	0.182
AM-ACUTE VS. OBTUSE	3.977	44.995	0.002	0.738
AM-ACUTE	0.469	0.356	0.799	0.284
AM-OBTUSE	3.137	1.443	0.010	-0.679

DISCRIMINANT SCORES

CONTRAST	1
1	0.749
2	0.509
3	-0.202
4	-0.186
5	-0.624

TEST OF SEX

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DF HYP	DF ERR	P LESS THAN	R
1 THROUGH 1	1.019	4.000	168.000	0.399	0.154

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 171)	MEAN SQ	P LESS THAN	1
AM-RIGHT VS. ACUTE	0.963	110.608	0.328	0.480
AM-ACUTE VS. OBTUSE	0.641	7.255	0.424	0.383
AM-ACUTE	2.406	1.826	0.123	0.766
AM-OBTUSE	0.250	0.115	0.618	0.142

V. GRADE EFFECTS FOR COPYING ANGLES, WITH ANGLE MATCHING COVARIED

SPECIAL CONTRASTS

	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
A1	0.50000	0.50000	-0.25000	-0.25000	-0.25000	-0.25000
A2	0.0	0.0	-3.00000	-1.00000	1.00000	3.00000
A3	1.00000	-1.00000	0.0	0.0	0.0	0.0
A4	0.0	0.0	1.00000	-1.00000	-1.00000	1.00000
A5	0.0	0.0	-1.00000	3.00000	-3.00000	1.00000

A1= GRADE 1 AND 2 VS. GRADE 3, 4, 5, AND 6
A2= LINEAR TREND IN GRADE 3 THROUGH 6
A3= GRADE 1 VS. 2
A4= QUADRATIC TREND IN GRADE 3 THROUGH 6
A5= CUBIC TREND IN GRADE 3 THROUGH 6

1. SPECIAL GRADE EFFECTS FOR ANGLE COPYING
(O COVARIATES)

TEST OF A1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	3.499	5.000	173.000	0.005**	0.303

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	4.217	146.921	0.041	0.429
AC-AVO	5.123	580.520	0.025	0.604
AC-ACUTE	4.637	132.799	0.033	0.481
AC-OBTUSE	0.110	9.901	0.741	-0.327
PARALLEL	4.220	168.198	0.041	0.513

TEST OF A2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	3.899	5.000	173.000	0.002**	0.318

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	1.691	58.902	0.195	0.209
AC-AVO	8.590	973.483	0.004	0.593
AC-ACUTE	1.061	30.380	0.304	0.208
AC-OBTUSE	3.208	289.453	0.075	0.053
PARALLEL	9.811	391.028	0.002	0.685

TEST OF A3+A4+A5

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 3	1.026	15.000	477.978	0.426	0.209
2 THROUGH 3	0.936	8.000	347.000	0.486	0.176
3 THROUGH 3	0.648	3.000	174.000	0.585	0.105

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(3, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	0.173	6.020	0.915	-0.022
AC-AVO	1.526	172.898	0.209	-0.910
AC-ACUTE	0.593	16.991	0.620	-0.407
AC-OBTUSE	0.756	68.232	0.520	0.764
PARALLEL	1.225	48.836	0.302	-0.142

2. SPECIAL GRADE EFFECTS FOR ANGLE COPYING (4 COVARIATES)

TEST OF WITHIN CELLS REGRESSION

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 4	0.615	16.000	519.996	0.873	0.173
2 THROUGH 4	0.515	9.000	451.569	0.864	0.127
3 THROUGH 4	0.457	4.000	342.000	0.767	0.101
4 THROUGH 4	0.062	1.000	171.500	0.804	0.019

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(4, 173)	MEAN SQ	P LESS THAN	1
AC-RVA	0.639	22.440	0.635	0.604
AC-AVO	0.862	97.959	0.488	-0.705
AC-ACUTE	0.186	5.437	0.945	0.132
AC-OBTUSE	0.791	71.741	0.532	-0.287

RAW REGRESSION COEFFICIENTS

	VARIATES			
COVARIATES	AC-RVA	AC-AVO	AC-ACUTE	AC-OBTUSE
AM-RVA	0.016	0.007	-0.018	-0.075
AM-AVO	0.101	0.143	-0.044	0.194
AM-ACUTE	-0.663	1.601	-0.186	0.487
AM-OBTUSE	-0.177	-0.659	0.321	-1.142

TEST OF A1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	2.519	4.000	170.000	0.043*	0.237

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 173)	MEAN SQ	P LESS THAN	1
AC-RVA	2.649	93.051	0.105	0.434
AC-AVO	2.521	286.641	0.114	0.601
AC-ACUTE	5.139	149.930	0.025	0.661
AC-OBTUSE	0.010	0.898	0.921	-0.413

TEST OF A2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	2.413	4.000	170.000	0.051	0.232

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 173)	MEAN SQ	P LESS THAN	1
AC-RVA	1.769	62.129	0.185	0.295
AC-AVO	7.720	877.578	0.006	0.795
AC-ACUTE	1.118	32.605	0.292	0.248
AC-OBTUSE	2.929	265.535	0.089	0.158

TEST OF A3+A4+A5

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 3	0.905	12.000	450.069	0.542	0.202
2 THROUGH 3	0.614	6.000	341.000	0.719	0.121
3 THROUGH 3	0.588	2.000	171.000	0.556	0.083

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(3, 173)	MEAN SQ	P LESS THAN	1
AC-RVA	0.145	5.083	0.933	0.081
AC-AVO	1.528	173.691	0.209	0.972
AC-ACUTE	0.530	15.453	0.662	0.322
AC-OBTUSE	0.797	72.263	0.497	-0.713

3. ADDITIONAL SPECIAL GRADE EFFECTS FOR ANGLE COPYING

SPECIAL CONTRASTS

	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
A1	-0.25000	-0.25000	-0.25000	-0.25000	0.50000	0.50000
A2	-3.00000	-1.00000	1.00000	3.00000	0.0	0.0
A3	0.0	0.0	0.0	0.0	1.00000	-1.00000
A4	1.00000	-1.00000	-1.00000	1.00000	0.0	0.0
A5	-1.00000	3.00000	-3.00000	1.00000	0.0	0.0

A1= GRADE 1, 2, 3, AND 4 VS. GRADE 5 AND 6
A2= LINEAR TREND IN GRADE 1 THROUGH 4
A3= GRADE 5 VS. 6
A4= QUADRATIC TREND IN GRADE 1 THROUGH 4
A5= CUBIC TREND IN GRADE 1 THROUGH 4

TEST OF A1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	4.604	5.000	173.000	0.001**	0.343

UNIVARIATE F TESTS

VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	4.803	167.312	0.030	0.368
AC-AVO	10.436	1182.721	0.001	0.606
AC-ACUTE	2.087	59.767	0.150	0.248
AC-OBYUSE	3.796	342.427	0.053	0.024
PARALLEL	8.351	332.850	0.004	0.583

TEST OF A2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.810	5.000	173.000	0.113	0.223

UNIVARIATE F TESTS

VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	1.361	47.420	0.245	0.391
AC-AVO	0.245	27.746	0.621	0.347
AC-ACUTE	2.435	69.740	0.120	0.531
AC-OBYUSE	0.931	83.998	0.336	-0.628
PARALLEL	2.664	106.165	0.104	0.601

TEST OF A3

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.353	5.000	173.000	0.245	0.194

UNIVARIATE F TESTS

VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	0.064	2.244	0.800	0.219
AC-AVO	1.006	114.056	0.317	-0.331
AC-ACUTE	1.731	49.584	0.190	-0.554
AC-OBYUSE	0.509	45.948	0.476	-0.063
PARALLEL	3.823	152.363	0.052	-0.751

TEST OF A4

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	2.083	5.000	173.000	0.070	0.238

UNIVARIATE F TESTS

VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	0.236	8.221	0.628	0.148
AC-AVO	6.291	712.933	0.013	0.984
AC-ACUTE	0.902	25.838	0.344	0.313
AC-OBYUSE	0.271	24.442	0.603	-0.617
PARALLEL	0.290	11.550	0.591	0.198

TEST OF A5

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.693	5.000	173.000	0.629	0.140

UNIVARIATE F TESTS

VARIABLE	F(1, 177)	MEAN SQ	P LESS THAN	1
AC-RVA	0.031	1.065	0.861	0.021
AC-AVO	0.503	56.973	0.479	0.386
AC-ACUTE	0.375	10.731	0.541	0.270
AC-OBYUSE	0.068	6.094	0.795	0.033
PARALLEL	2.684	106.963	0.103	-0.874

4. ADDITIONAL SPECIAL GRADE EFFECTS FOR ANGLE COPYING

SPECIAL CONTRASTS

	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
A1	-5.00000	-3.00000	-1.00000	1.00000	3.00000	5.00000
A2	5.00000	-1.00000	-4.00000	-4.00000	-1.00000	5.00000
A3	-5.00000	7.00000	4.00000	-4.00000	-7.00000	5.00000
A4	-1.00000	1.00000	0.0	0.0	0.0	0.0
A5	0.0	0.0	0.0	0.0	-1.00000	1.00000

A1= OVERALL LINEAR TREND
A2= OVERALL QUADRATIC TREND
A3= OVERALL CUBIC TREND
A4= GRADE 1 VS. 2
A5= GRADE 5 VS. 6

TEST OF A1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	6.054	5.000	173.000	0.001	0.386

VARIABLE	UNIVARIATE F TESTS F(1, 177)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	5.657	197.072	0.018	0.360
AC-AVO	9.551	1082.361	0.002	0.562
AC-ACUTE	4.996	143.087	0.027	0.375
AC-OBYUSE	1.475	133.095	0.226	-0.159
PARALLEL	12.749	508.163	0.001	0.652

TEST OF A2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.200	5.000	173.000	0.311	0.183

VARIABLE	UNIVARIATE F TESTS F(1, 177)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	0.000	0.016	0.983	-0.120
AC-AVO	4.591	520.256	0.033	0.724
AC-ACUTE	0.109	3.125	0.742	0.116
AC-OBYUSE	2.545	229.566	0.112	0.343
PARALLEL	0.969	38.631	0.326	0.348

TEST OF A3

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.236	5.000	173.000	0.294	0.186

VARIABLE	UNIVARIATE F TESTS F(1, 177)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	0.696	24.243	0.405	0.382
AC-AVO	3.133	355.003	0.078	0.932
AC-ACUTE	0.027	0.780	0.869	0.032
AC-OBYUSE	0.296	26.678	0.587	-0.628
PARALLEL	0.542	21.607	0.463	-0.270

TABLE VI

GRADE AND ORDER EFFECTS FOR COPYING PARALLEL LINES

Source	DF	MS	F	P Less Than
Within cells	149	40.996		
Grade	5	140.155	3.419	0.006**
Order	5	60.355	1.472	0.202

TABLE VII

GRADE AND SEX EFFECTS FOR COPYING PARALLEL LINES

Source	DF	MS	F	P Less Than
Within cells	171	38.479		
Grade	5	140.155	3.642	0.004**
Sex	1	0.107	0.003	0.958
Grade x sex	5	94.945	2.467	0.035*

** indicates 1% level of significance; * indicates 5% level.

VIII. GRADE AND SEX EFFECTS FOR ALL FIVE TRANSFORMED COPYING VARIABLES, COVARYING IQ

TEST OF WITHIN CELLS REGRESSION

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.696	5.000	166.000	0.138	0.220

VARIABLE	UNIVARIATE F TESTS F(1, 170)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	0.306	10.621	0.581	0.106
AC-AVO	0.025	2.084	0.869	-0.293
AC-ACUTE	0.092	2.582	0.762	-0.201
AC-OBTUSE	2.480	221.216	0.117	0.719
PARALLEL	4.514	170.199	0.035	-0.779

RAW REGRESSION COEFFICIENTS

COVARIATES	VARIATES AC-RVA	AC-AVO	AC-ACUTE	AC-OBTUSE	PARALLEL
IQ	0.007	-0.003	-0.004	0.034	-0.030

TEST OF GRADE X SEX

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 5	1.533	25.000	618.165	0.048*	0.307
2 THROUGH 5	1.325	16.000	553.510	0.176	0.262
3 THROUGH 5	1.009	9.000	461.654	0.432	0.200
4 THROUGH 5	0.544	4.000	335.000	0.704	0.086
5 THROUGH 5	0.944	1.000	168.000	0.333	0.075

VARIABLE	UNIVARIATE F TESTS F(5, 170)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	1.344	46.559	0.248	0.135
AC-AVO	0.562	59.932	0.729	0.525
AC-ACUTE	1.826	51.330	0.110	0.134
AC-OBTUSE	1.044	93.095	0.393	-0.409
PARALLEL	2.672	100.752	0.024	-0.831

TEST OF GRADE

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 5	2.067	25.000	618.165	0.002**	0.438
2 THROUGH 5	0.906	16.000	553.510	0.563	0.166
3 THROUGH 5	0.950	9.000	461.654	0.461	0.177
4 THROUGH 5	0.786	4.000	335.000	0.535	0.104
5 THROUGH 5	1.305	1.000	168.000	0.255	0.088

VARIABLE	UNIVARIATE F TESTS F(5, 170)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
AC-RVA	1.366	47.328	0.240	0.296
AC-AVO	3.698	394.161	0.003	0.668
AC-ACUTE	1.446	40.632	0.210	0.377
AC-OBTUSE	1.385	123.543	0.232	-0.224
PARALLEL	3.670	138.357	0.004	0.608

TEST OF SEX

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	3.353	5.000	166.000	0.007**	0.303

VARIABLE	UNIVARIATE F TESTS F(1, 170)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
AC-RVA	0.365	29.980	0.354	0.171
AC-AVO	15.355	1636.719	0.001	1.000
AC-ACUTE	1.101	30.945	0.295	0.241
AC-OBTUSE	1.479	131.930	0.226	-0.153
PARALLEL	0.025	0.949	0.874	0.001

TABLE IX

SUMMARY TABLES FOR ANALYSES IN WHICH THE FIVE TRANSFORMED COPYING VARIABLES ARE COVARIED

	Source of Variation	DF	MS	F	Significance Level
Analysis of stages of drawing the solid cube	Grade	5	1534.367	11.786	0.001
	Sex	1	976.235	7.499	0.007
	Grade x sex	5	62.649	0.481	0.790
	Error	123	130.187		
Analysis of solid stages, covarying the five transformed copying variables	Regression	5	196.356	1.316	0.259
	Grade	5	1280.954	8.586	0.001
	Sex	1	536.281	3.594	0.060
	Grade x sex	5	44.413	0.298	0.914
	Error	166	149.198		
Analysis of stages of copying the oblique projection	Grade	5	1047.293	11.888	0.001
	Sex	1	61.484	0.698	0.405
	Grade x sex	5	134.326	1.525	0.187
	Error	123	88.096		
Analysis of oblique stages, covarying the five transformed copying variables	Regression	5	127.745	1.478	0.202
	Grade	5	792.551	9.171	0.001
	Error	118	86.416		
Analysis of stages of copying the isometric projection	Grade	5	455.255	4.132	0.002
	Sex	1	125.674	1.166	0.282
	Grade x sex	5	156.433	1.452	0.211
	Error	123	107.759		
Analysis of isometric stages, covarying the five transformed copying variables	Regression	5	188.400	1.806	0.117
	Grade	5	277.490	2.659	0.026
	Error	118	104.342		
Analysis of stages of drawing the mock-cube	Grade	5	2055.716	10.110	0.001
	Sex	1	1757.521	8.643	0.004
	Grade x sex	5	276.710	1.361	0.241
	Error	171	203.344		
Analysis of mock-cube stages, covarying the five transformed copying variables	Regression	5	772.330	4.148	0.001
	Grade	5	1180.090	6.338	0.001
	Sex	1	862.859	4.634	0.033
	Grade x sex	5	231.215	1.242	0.292
	Error	166	186.205		

X. SUMMARY TABLES FOR ANALYSES COMPARING THE STAGES OF DRAWING THE DIFFERENT CUBE STIMULI

A. Average values of transformed stage variables

FACTOR GRADE			OVI absolute value of the difference between the stage at which the oblique projection was copied and the stage at which the isometric projection was copied	SVO absolute value of the difference between the stage of the solid cube drawing and the stage at which the oblique projection was copied	SVI absolute value of the difference between the stage of the solid cube drawing and the stage at which the isometric projection was copied
1	30 OBS				
		M	4.500	11.167	12.667
		SD	6.740	7.621	10.807
2	30 OBS				
		M	5.500	11.333	13.167
		SD	7.583	8.899	11.780
3	30 OBS				
		M	8.167	13.167	11.333
		SD	7.711	10.626	11.059
4	32 OBS				
		M	7.500	11.719	10.469
		SD	6.839	11.188	10.951
5	31 OBS				
		M	8.710	11.129	8.871
		SD	7.524	11.008	8.728
6	30 OBS				
		M	5.833	8.700	9.867
		SD	5.266	10.001	10.265

		SVOI absolute value of the difference between the stage of the solid cube drawing and the average of the stages at which the oblique and isometric projections were copied	MVOI absolute value of the difference between the stage of the mock-cube drawing and the average of the stages at which the oblique and isometric projections were copied	MVS absolute value of the difference between the stage of the solid cube drawing and the stage of the mock-cube drawing
1				
	M	11.917	16.750	16.667
	SD	8.451	10.195	10.775
2				
	M	11.917	10.917	15.167
	SD	9.797	7.585	9.955
3				
	M	11.583	12.750	13.500
	SD	10.139	7.610	9.662
4				
	M	10.781	13.750	19.375
	SD	10.188	10.492	12.684
5				
	M	9.677	10.484	10.968
	SD	8.533	6.272	12.344
6				
	M	9.283	7.083	12.700
	SD	9.344	6.162	8.891

B. Analysis of variance of SVOI and OVI according to the children's grade

TEST OF GRADES 1 AND 2 VS. GRADES 3 THROUGH 6

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.249	2.000	176.000	0.289	0.118

VARIABLE	UNIVARIATE F TESTS F(1, 177)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
CS-SVOI	2.131	118.044	0.146	0.938
CS-OVI	0.306	9.882	0.581	0.390

TEST OF LINEAR TREND IN GRADES 3 THROUGH 6

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	5.033	2.000	176.000	0.007**	0.233

VARIABLE	UNIVARIATE F TESTS F(1, 177)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
CS-SVOI	1.011	55.977	0.316	-0.358
CS-OVI	8.832	285.425	0.003**	-0.950

C. Analysis of variance of SVOI and OVI according to the children's grade, covarying the children's graphic skills

TEST OF WITHIN CELLS REGRESSION

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 2	5.457	10.000	342.000	0.001**	0.484
2 THROUGH 2	1.269	4.000	344.000	0.282	0.170

VARIABLE	UNIVARIATE F TESTS F(5, 172)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
CS-SVOI	7.452	349.107	0.001**	0.907
CS-OVI	2.876	88.259	0.016*	0.574

RAW REGRESSION COEFFICIENTS

COVARIATES	VARIATES CS-SVOI	CS-OVI
AC-RVA	0.024	0.032
AC-AVO	-0.049	0.087
AC-ACUTE	-0.013	-0.063
AC-OBTUSE	0.050	-0.048
PARALLEL	0.485	0.201

TEST OF GRADES 1 AND 2 VS. GRADES 3 THROUGH 6

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.290	2.000	171.000	0.749	0.058

VARIABLE	UNIVARIATE F TESTS F(1, 172)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
CS-SVOI	0.578	27.059	0.448	0.981
CS-OVI	0.033	1.027	0.855	-0.096

TEST OF LINEAR TREND IN GRADES 3 THROUGH 6

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.804	2.000	171.000	0.168	0.144

VARIABLE	UNIVARIATE F TESTS F(1, 172)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
CS-SVOI	0.045	2.113	0.832	0.035
CS-OVI	3.625	111.266	0.059	1.005

XI. ANALYSES USING DRAWING STAGE AS THE INDEPENDENT VARIABLE

Special Contrasts:

1 = Stage 1 vs. Stages 2, 3, 4, and 5
2 = Stage 2 vs. Stages 3 and 4
3 = Stage 3 vs. Stage 4
4 = linear trend over all five stages

A. STAGE OF THE CHILD'S DRAWING OF THE SOLID CUBE USED AS THE INDEPENDENT VARIABLE

TEST OF A1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	3.488	6.000	125.000	0.003	0.379

UNIVARIATE F TESTS / STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS

VARIABLE	F(1, 130)	MEAN SQ	P LESS THAN	1
AC-RVA	1.841	64.060	0.177	0.089
AC-AVO	10.274	1278.320	0.002	0.636
AC-ACUTE	4.572	125.509	0.034	0.372
AC-OBTUSE	6.269	534.809	0.014	0.213
PARALLEL	1.244	55.518	0.267	0.187
MATCH	4.388	4.668	0.038	-0.461

TEST OF A2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.666	6.000	125.000	0.135	0.272

UNIVARIATE F TESTS / STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS

VARIABLE	F(1, 130)	MEAN SQ	P LESS THAN	1
AC-RVA	0.867	30.163	0.354	0.399
AC-AVO	0.904	112.486	0.344	-0.463
AC-ACUTE	0.646	17.733	0.423	0.224
AC-OBTUSE	0.004	0.352	0.949	0.165
PARALLEL	0.769	34.328	0.382	-0.256
MATCH	5.484	5.833	0.021	0.862

TEST OF A3

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.620	6.000	125.000	0.714	0.170

UNIVARIATE F TESTS / STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS

VARIABLE	F(1, 130)	MEAN SQ	P LESS THAN	1
AC-RVA	0.652	22.674	0.421	0.504
AC-AVO	0.209	25.973	0.649	-0.118
AC-ACUTE	0.439	12.061	0.509	-0.402
AC-OBTUSE	0.530	45.258	0.468	-0.402
PARALLEL	1.578	70.389	0.211	0.668
MATCH	0.253	0.269	0.616	-0.214

TEST OF A4

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.144	6.000	125.000	0.990	0.083

UNIVARIATE F TESTS / STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS

VARIABLE	F(1, 130)	MEAN SQ	P LESS THAN	1
AC-RVA	0.115	4.015	0.735	0.195
AC-AVO	0.052	6.480	0.820	0.127
AC-ACUTE	0.407	11.164	0.525	0.578
AC-OBTUSE	0.151	12.873	0.698	0.238
PARALLEL	0.334	14.917	0.564	0.570
MATCH	0.076	0.080	0.784	-0.219

O. STAGE OF THE CHILD'S COPY OF THE OBLIQUE PROJECTION USED AS THE INDEPENDENT VARIABLE

TEST OF 01

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	2.470	6.000	125.000	0.027	0.326

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	4.350	151.326	0.039	0.460
AC-AVO	1.669	207.703	0.199	0.002
AC-ACUTE	1.238	33.983	0.268	0.129
AC-OBTUSE	9.967	850.375	0.002	0.769
PARALLEL	0.458	20.443	0.500	0.159
MATCH	0.577	0.613	0.449	0.375

TEST OF 02

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.399	6.000	125.000	0.220	0.251

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	0.477	16.599	0.491	0.405
AC-AVO	2.011	250.211	0.159	-0.464
AC-ACUTE	5.574	152.994	0.020	-0.839
AC-OBTUSE	0.456	38.912	0.501	-0.040
PARALLEL	0.019	0.849	0.890	0.109
MATCH	0.008	0.009	0.927	0.060

TEST OF 03

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	3.126	6.000	125.000	0.007	0.361

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	0.842	29.284	0.361	0.048
AC-AVO	0.623	77.527	0.431	0.392
AC-ACUTE	1.700	46.675	0.195	0.304
AC-OBTUSE	0.276	23.561	0.600	-0.403
PARALLEL	0.495	22.093	0.483	-0.195
MATCH	13.325	14.173	0.001	-0.909

TEST OF 04

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	3.004	6.000	125.000	0.009	0.355

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	1.437	49.995	0.233	0.281
AC-AVO	0.028	3.441	0.868	-0.317
AC-ACUTE	0.043	1.173	0.837	-0.154
AC-OBTUSE	10.420	889.006	0.002	0.903
PARALLEL	0.551	24.594	0.459	-0.158
MATCH	2.837	3.018	0.094	0.582

I. STAGE OF THE CHILD'S COPY OF THE ISOMETRIC PROJECTION USED AS THE INDEPENDENT VARIABLE

TEST OF I1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	5.137	6.000	125.000	0.001	0.445

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	12.745	443.378	0.001	0.576
AC-AVO	2.119	263.650	0.148	0.018
AC-ACUTE	11.342	311.347	0.001	0.469
AC-OBTUSE	7.524	641.881	0.007	0.404
PARALLEL	0.277	12.363	0.600	0.070
MATCH	3.230	3.436	0.075	0.474

TEST OF I2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.671	6.000	125.000	0.673	0.177

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	1.190	41.392	0.277	0.662
AC-AVO	0.542	67.405	0.463	-0.259
AC-ACUTE	0.278	7.624	0.599	0.246
AC-OBTUSE	1.538	131.197	0.217	-0.594
PARALLEL	0.020	0.909	0.887	-0.055
MATCH	0.450	0.478	0.504	0.388

TEST OF I3

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.967	6.000	125.000	0.451	0.211

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	0.862	29.988	0.355	0.156
AC-AVO	0.145	18.034	0.704	0.174
AC-ACUTE	2.340	64.236	0.128	0.578
AC-OBTUSE	0.561	47.903	0.455	0.074
PARALLEL	0.133	5.928	0.716	-0.195
MATCH	3.151	3.351	0.078	-0.696

TEST OF I4

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.196	6.000	125.000	0.313	0.233

VARIABLE	UNIVARIATE F TESTS F(1, 130)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS 1
AC-RVA	1.242	43.200	0.267	0.373
AC-AVO	0.017	2.124	0.896	-0.284
AC-ACUTE	0.011	0.303	0.916	-0.076
AC-OBTUSE	4.456	380.210	0.037	0.876
PARALLEL	0.817	36.431	0.368	-0.325
MATCH	0.299	0.318	0.585	0.400

APPENDIX F

EXPERIMENTS 1 AND 3, T. HARRY GARRETT SCHOOL

I. STAGE USAGE FOR DRAWING THE MOCK-CUBE

II. CORRELATIONS OF CUBE TASKS WITH CHILDREN'S GRADE, AND INTERCORRELATIONS OF THE CUBE TASKS

III. INTERCORRELATIONS OF SCORES ON DIFFERENT CUBE TASKS, WITHIN EACH GRADE, AND CORRELATION OF TASKS WITH IQ

IV. ANALYSIS OF VARIANCE OF CUBE STAGES, COMPARING ORDERS OF PRESENTATION

V. ANALYSIS OF VARIANCE OF CUBE STAGES, ACCORDING TO GRADE AND SEX OF THE SUBJECT

VI. ANALYSIS OF VARIANCE OF CUBE AND MOCK-CUBE STAGES, COVARYING THE CHILDREN'S CUBES SCALE SCORE

TABLE I

STAGE USAGE FOR DRAWING THE MOCK-CUBE

Grade		Less Advanced	3	4	5
1	Frequency	6	13	4	0
	%	.261	.565	.174	.000
3	Frequency	2	13	9	5
	%	.069	.448	.310	.172
5	Frequency	0	8	16	6
	%	.000	.267	.533	.200
Total	Frequency	8	34	29	11
	%	.098	.415	.354	.134

II. CORRELATIONS OF CUBE TASKS WITH CHILDREN'S GRADE, AND INTERCORRELATIONS OF THE CUBES TASKS

A. for all subjects, with cubes scored by substage

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
GRADE	3406	2567	2817	4804	1889	5717	3.17	1.60
SOLID		5668	4982	3993	1724	5251	29.93	13.08
OBL			6379	5343	1359	6043	37.07	9.29
ISO				4563	-0698	5545	38.10	8.07
MOCK					0937	5913	38.71	9.55
MATCH						3282	3.25	0.99
CCS							9.53	2.98

B. for male subjects only

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
GRADE	4746	4346	2107	6008	3222	7075	3.24	1.62
SOLID		6286	5090	4746	0987	5360	32.31	13.51
OBL			5944	6006	-0688	5599	38.90	8.17
ISO				3736	-1671	5325	38.90	8.10
MOCK					0053	6439	39.87	10.27
MATCH						0876	3.41	0.94
CCS							9.97	2.83

C. for female subjects only

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
GRADE	1882	1065	3478	3372	0549	4483	3.09	1.61
SOLID		4926	4718	2734	1979	4429	27.56	12.35
OBL			6165	4689	2412	6195	35.24	10.05
ISO				5428	-0129	5644	37.31	8.06
MOCK					1535	5294	37.56	8.74
MATCH						5021	3.09	1.01
CCS							9.09	3.10

MATCH= CUBE AND BLOCK MATCHING
CCS= CHILDREN'S CUBES SCALE

III. INTERCORRELATIONS OF SCORES ON DIFFERENT CUBE TASKS, WITHIN EACH GRADE, AND CORRELATION OF TASKS WITH IQ

A. for all subjects, with cubes scored by substage

FIRST GRADE (N=23)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	0000	0000	0000	0000	0000	0000	0.00	0.00
SOLID		2158	0475	0945	0719	-2733	21.73	10.83
OBL			6272	7120	-2705	2875	32.60	6.71
ISO				3939	-3888	3249	33.91	8.25
MOCK					-2480	3657	31.52	11.71
MATCH						0843	2.86	1.17
CCS							6.52	2.08

THIRD GRADE (N=29)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	0982	0884	-1093	3108	1760	0404	10	23.97
SOLID		5765	3478	3615	-1671	4139	32.93	11.06
OBL			4790	3786	-2942	4498	38.79	8.41
ISO				1626	-3378	5724	39.65	6.53
MOCK					0145	5390	39.82	7.40
MATCH						-0526	3.44	0.73
CCS							10.48	2.09

FIFTH GRADE (N=30)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-0918	0048	1969	0790	2390	0674	90.40	38.90
SOLID		5835	6957	4378	2416	6725	33.33	14.04
OBL			6090	5016	4561	7329	38.83	10.80
ISO				5809	1314	5134	39.83	8.35
MOCK					3581	4784	43.16	5.79
MATCH						5096	3.36	0.99
CCS							10.93	2.69

FIRST GRADE BOYS (N=11)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
SOLID		-2613	-5097	-0934	2726	-5594	20.90909091	10.91287813
OBL			2741	5366	-2646	3098	33.18181818	4.62208139
ISO				1003	-2876	7481	35.90909091	7.35465220
MOCK					-2938	2697	29.09090909	11.36181903
MATCH						-2996	2.90909091	1.37510330
CCS							6.54545454	1.80906806

FIRST GRADE GIRLS (N=12)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
SOLID		4728	4906	2270	-1579	-0849	22.50000000	11.18033988
OBL			7887	8806	-3246	2832	32.08333333	8.38243112
ISO				6597	-5532	0959	32.08333333	8.90820197
MOCK					-2008	4479	33.75000000	12.08398639
MATCH						4426	2.83333333	1.02985730
CCS							6.50000000	2.39317210

THIRD GRADE BOYS (N=14)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	1174	0571	-1073	3633	1632	-1049	107.4285	33.62625870
SOLID		7945	4889	3952	-4406	4429	35.35714285	9.70017559
OBL			6006	4871	-4025	4618	39.64285714	9.49985540
ISO				3012	-4337	6947	39.64285714	5.70569409
MOCK					-3402	4660	42.50000000	7.27218092
MATCH						-5451	3.50000000	0.85485041
CCS							10.71428571	1.81568259

THIRD GRADE GIRLS (N=15)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	1599	2632	-2046	4594	3035	4340	108.5333	9.97043247
SOLID		3895	2810	2534	0560	3793	30.66666666	12.08197532
OBL			4030	2297	-1202	4525	38.00000000	7.51199532
ISO				0842	-2735	5113	39.66666666	7.43223353
MOCK					4172	6012	37.33333333	7.03731550
MATCH						3995	3.40000000	0.63245553
CCS							10.26666666	2.37446735

FIFTH GRADE BOYS (N=16)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	-0731	-0248	0945	-1617	3193	1006	82.25000000	43.27662956
SOLID		6363	8385	4376	-3255	7166	37.50000000	13.90443574
OBL			7389	5600	-1786	3541	42.18750000	7.06369827
ISO				5132	-2547	4463	40.31250000	10.07782218
MOCK					-2542	2405	45.00000000	5.47722557
MATCH						0301	3.68750000	0.47871355
CCS							11.68750000	2.02381652

FIFTH GRADE GIRLS (N=14)

	SOLID	OBL	ISO	MOCK	MATCH	CCS	MEANS,	STANDARD DEVIATION
IQ	0673	2011	5312	6819	4764	2144	99.71428571	32.26674537
SOLID		5143	5119	2847	3844	6099	28.57142857	13.07207408
OBL			7122	3909	5168	8447	35.00000000	13.15597029
ISO				8034	4321	7367	39.28571428	6.15727926
MOCK					5271	5615	41.07142857	5.60956879
MATCH						5820	3.00000000	1.30088727
CCS							10.07142857	3.14921933

TABLE IV

ANALYSIS OF VARIANCE OF CUBE STAGES,
COMPARING ORDERS OF PRESENTATION

Source of Variation	DF	Mean Square	F	Significance Level
Order	3	170.614	1.358	0.265
Grade	2	1075.858	8.565	0.001
Grade x Order	6	226.272	1.801	0.115
Error	58	125.611		

TABLE V

ANALYSIS OF VARIANCE OF CUBE STAGES, ACCORDING TO GRADE AND SEX OF THE SUBJECT

Source of Variation	DF	Mean Square	F	Significance Level
A. Drawing a Picture of a Solid Cube				
Sex	1	463.721	3.692	0.060
Grade	2	1075.858	8.565	0.001
Grade x Sex	2	179.803	1.431	0.247
Error	58	125.611		
B. Copying the Oblique Projection				
Sex	1	274.392	4.452	0.039
Grade	2	318.578	5.169	0.009
Grade x Sex	2	79.800	1.295	0.282
Error	58	61.638		
C. Copying the Isometric Projection				
Sex	1	51.524	0.879	0.352
Grade	2	281.735	4.806	0.012
Grade x Sex	2	24.729	0.422	0.658
Error	58	58.621		

TABLE V--Continued

D. Drawing the Mock-Cube

Source of Variation	DF	Mean Square	F	Significance Level
Sex	1	110.066	1.812	0.184
Grade	2	910.237	14.982	0.001
Grade x Sex	2	117.420	2.920	0.062
Error	58	60.754		

TABLE VI

ANALYSIS OF VARIANCE OF CUBE AND MOCK-CUBE STAGES, COVARYING THE CHILDREN'S CUBES SCALE SCORE

Source of Variance	DF	Mean Square	F	Significance Level
Solid Cube				
Regression of Children's Cubes Scale	1	379.137	3.129	0.082
Grade	2	161.850	1.336	0.271
Sex	1	265.320	2.190	0.144
Grade x Sex	2	119.775	0.989	0.378
Error	57	121.163		
Oblique Projection				
Regression of Children's Cubes Scale	1	573.579	10.893	0.002
Grade	2	2.872	0.055	0.947
Sex	1	108.105	2.053	0.157
Grade x Sex	2	33.168	0.630	0.536
Error	57	52.657		
Isometric Projection				
Regression of Children's Cubes Scale	1	620.187	12.717	0.001
Grade	2	3.057	0.063	0.939
Sex	1	1.107	0.023	0.881
Grade x Sex	2	48.425	0.993	0.377
Error	57	48.769		

TABLE VI--Continued

Source of Variance	DF	Mean Square	F	Significance Level
Mock-Cube				
Regression of Children's Cubes Scale	1	529.498	10.080	0.002
Grade	2	109.998	2.094	0.133
Sex	1	22.288	0.424	0.517
Grade x Sex	2	139.859	2.662	0.078
Error	57	52.531		

APPENDIX G

EXPERIMENT 2, T. HARRY GARRETT SCHOOL

I. ANGLE COPYING DATA

II. ANGLE MATCHING DATA

III. PARALLEL LINES DATA

IV. GRADE AND SEX EFFECTS FOR COPYING ANGLES AND PARALLEL LINES

V. GRADE EFFECTS FOR COPYING ANGLES, WITH ANGLE MATCHING COVARIED

VI. SUMMARY TABLES FOR ANALYSES IN WHICH THE FIVE TRANSFORMED COPYING VARIABLES ARE COVARIED

VII. ANALYSES USING DRAWING STAGE AS THE INDEPENDENT VARIABLE

TABLE I

ANGLE COPYING DATA

A. Mean Scores

Angle		Grade 1	Grade 3	Grade 5	Average
15^o	av. size of angle drawn	30.48	20.28	21.10	23.44
	s.d. of angle size	13.75	10.42	6.95	11.22
30^o	av. size of angle drawn	39.48	28.45	32.27	32.94
	s.d. of angle size	13.51	11.85	9.11	12.14
45^o	av. size of angle drawn	47.39	35.21	40.60	40.60
	s.d. of angle size	14.07	20.87	9.88	16.21
60^o	av. size of angle drawn	50.22	49.03	47.00	48.62
	s.d. of angle size	14.77	15.72	12.06	14.09
75^o	av. size of angle drawn	57.65	61.38	64.13	61.34
	s.d. of angle size	19.71	18.60	11.09	16.61
90^o	av. size of angle drawn	83.52	81.66	90.47	85.40
	s.d. of angle size	10.56	23.65	6.66	15.97
105^o	av. size of angle drawn	96.70	97.31	107.17	100.74
	s.d. of angle size	20.30	30.59	15.71	23.41
120^o	av. size of angle drawn	97.74	103.41	116.13	106.48
	s.d. of angle size	21.69	38.20	14.26	27.65
135^o	av. size of angle drawn	114.65	119.41	127.40	121.00
	s.d. of angle size	22.51	35.81	15.64	26.38
150^o	av. size of angle drawn	114.70	128.72	135.60	127.30
	s.d. of angle size	22.59	38.28	15.21	28.27

TABLE I--Continued

B. Angles arranged in order, according to how well the size of the angle drawn matched the size of the stimulus angle	
Most accurately copied	90°
	30°
	15°
	45°
	60°
	105°
	120°
	75°
	135°
Least accurately copied	150°

TABLE II

ANGLE MATCHING DATA

A. Average size of angles chosen

Angle		Grade 1	3	5	Average
15^{o}	av. size of angle chosen	18.91	15.52	16.00	16.65
	s.d. of angle size	6.73	2.78	3.80	4.72
30^{o}	av. size of angle chosen	28.70	30.52	31.00	30.18
	s.d. of angle size	10.02	6.32	5.48	7.26
45^{o}	av. size of angle chosen	40.43	38.79	40.50	39.88
	s.d. of angle size	10.54	7.52	8.94	8.89
60^{o}	av. size of angle chosen	53.48	54.31	54.00	53.96
	s.d. of angle size	14.88	10.15	9.32	11.27
75^{o}	av. size of angle chosen	72.39	70.34	68.00	70.06
	s.d. of angle size	19.53	10.68	15.12	15.10
90^{o}	av. size of angle chosen	86.09	90.00	89.00	88.54
	s.d. of angle size	10.33	4.01	3.81	6.50
105^{o}	av. size of angle chosen	109.56	107.07	107.00	107.74
	s.d. of angle size	19.94	12.50	11.64	14.55
120^{o}	av. size of angle chosen	115.43	117.41	118.00	117.07
	s.d. of angle size	21.89	7.02	10.95	13.83
135^{o}	av. size of angle chosen	137.61	135.52	136.00	136.28
	s.d. of angle size	11.66	11.68	11.77	11.60
150^{o}	av. size of angle chosen	144.78	145.86	145.50	145.43
	s.d. of angle size	9.71	7.91	14.82	11.23

TABLE II--Continued

B. Angles arranged in order, according to how well each one was matched	
Most often matched correctly	15°
	90°
	30°
	150°
	45°
	105°
	120°
	135°
	60°
Least often matched correctly	75°

TABLE III

PARALLEL LINES DATA

Line Direction		Grade 1	3	5	Average
Horizontal	av. angular separation	4.48	2.03	1.93	2.68
	s.d. of ang. sep.	4.03	1.70	1.44	2.73
Vertical	av. angular separation	2.87	1.83	1.97	2.17
	s.d. of ang. sep.	1.94	1.56	1.75	1.78
Diagonal	av. angular separation	4.83	2.10	3.57	3.40
	s.d. of ang. sep.	4.43	1.74	3.21	3.35
Average	av. angular separation	4.06	1.99	2.49	2.75
	s.d. of ang. sep.	3.68	1.65	2.37	2.73

TABLE IV

GRADE AND SEX EFFECTS FOR COPYING ANGLES AND PARALLEL LINES

TEST OF GRADE

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 2	2.075	10.000	108.000	0.033	0.463
2 through 2	1.596	4.000	54.500	0.189	0.324

		Univariate F tests		Standardized discriminant
Variable	F(2, 58)	Mean Sq	P less than	function coefficients
AC-RVA	3.647	231.004	0.032	0.657
AC-AVO	2.521	515.626	0.089	-0.058
AC-ACUTE	2.618	127.516	0.082	0.343
AC-OBTUSE	0.459	15.901	0.634	-0.235
PARALLEL	4.504	28.590	0.015	0.626

TEST OF SEX

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 1	2.022	5.000	54.000	0.090	0.397

		Univariate F tests		Standardized discriminant
Variable	F(1, 58)	Mean Sq	P less than	function coefficients
AC-RVA	0.376	23.793	0.542	1.208
AC-AVO	2.517	514.854	0.118	-1.258
AC-ACUTE	0.325	15.827	0.571	-0.373
AC-OBTUSE	1.112	38.534	0.296	-0.341
PARALLEL	0.043	0.270	0.837	0.069

TEST OF GRADE x SEX

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 2	1.065	10.000	108.000	0.396	0.402
2 through 2	0.158	4.000	54.500	0.959	0.107

		Univariate F tests		Standardized discriminant
Variable	F(2, 58)	Mean Sq	P less than	function coefficients
AC-RVA	0.815	51.603	0.448	0.757
AC-AVO	0.146	29.772	0.865	-0.791
AC-ACUTE	0.983	47.858	0.380	0.446
AC-OBTUSE	0.735	25.460	0.484	0.406
PARALLEL	1.573	9.982	0.216	-0.536

AC-RVA = Difference between accuracy of copying right angles and acute angles
AC-AVO = Difference between accuracy of copying acute and obtuse angles
AC-ACUTE = Differences among the acute angles in accuracy of copying
AC-OBTUSE = Differences among the obtuse angles in accuracy of copying
PARALLEL = Differences between orthogonal and oblique lines in parallelism

TABLE V

GRADE EFFECTS FOR COPYING ANGLES, WITH ANGLE MATCHING COVARIED

A. Angle Matching

TEST OF GRADE

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 2	3.071	8.000	110.000	0.004	0.528
2 through 2	1.474	3.000	55.500	0.232	0.272

Variable	F(2, 58)	Univariate F tests Mean Sq	P less than	Standardized discriminant function coefficients
AM-RVA	5.843	127.651	0.005	0.659
AM-AVO	1.896	21.121	0.159	-0.118
AM-ACUTE	0.969	23.062	0.385	-0.221
AM-OBTUSE	6.960	278.100	0.002	0.737

TEST OF SEX

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 1	1.946	4.000	55.000	0.116	0.352

Variable	F(1, 58)	Univariate F tests Mean Sq	P less than	Standardized discriminant function coefficients
AM-OBTUSE	7.687	307.140	0.007	0.907

TEST OF GRADE x SEX

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 2	1.303	8.000	110.000	0.250	0.361
2 through 2	0.782	3.000	55.500	0.509	0.201

B. Angle copying, with Angle Matching covaried

TEST OF WITHIN CELLS REGRESSION

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 4	1.335	16.000	156.445	0.182	0.485
2 through 4	0.722	9.000	136.725	0.688	0.326
3 through 4	0.139	4.000	104.000	0.967	0.103
4 through 4	0.0	1.000	52.500	1.000	0.001

Variable	F(4, 54)	Univariate F tests Mean Sq	P less than	Standardized discriminant function coefficients
AC-RVA	0.207	13.892	0.933	1.218
AC-AVO	0.888	182.932	0.478	-1.227
AC-ACUTE	0.400	20.341	0.807	-0.128
AC-OBTUSE	2.109	67.880	0.092	-0.606

TABLE V--Continued

TEST OF GRADE

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 2	2.137	8.000	102.000	0.039	0.449
2 through 2	1.512	3.000	51.500	0.223	0.284

		Univariate F tests		Standardized discriminant
Variable	F(2, 54)	Mean Sq	P less than	function coefficients
AC-RVA	2.916	195.360	0.063	0.977
AC-AVO	2.184	450.238	0.122	-0.330
AC-ACUTE	2.193	111.410	0.121	0.368
AC-OBTUSE	1.486	47.835	0.235	-0.619

TEST OF SEX

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 1	1.476	4.000	51.000	0.223	0.322

		Univariate F tests		Standardized discriminant
Variable	F(1, 54)	Mean Sq	P less than	function coefficients
AC-RVA	0.099	6.619	0.755	1.305
AC-AVO	1.345	277.227	0.251	-1.380
AC-ACUTE	0.414	21.041	0.523	-0.451
AC-OBTUSE	0.376	12.103	0.542	-0.326

TEST OF GRADE x SEX

Tests of significance using Wilks Lambda criterion and canonical correlations

Test of roots	F	DFHYP	DFERR	P less than	R
1 through 2	0.585	8.000	102.000	0.788	0.292
2 through 2	0.008	3.000	51.500	0.999	0.021

		Univariate F tests		Standardized discriminant
Variable	F(2, 54)	Mean Sq	P less than	function coefficients
AC-RVA	0.447	29.934	0.642	0.883
AC-AVO	0.029	5.949	0.972	-0.858
AC-ACUTE	0.982	49.892	0.381	0.531
AC-OBTUSE	0.546	17.563	0.583	0.445

TABLE VI

SUMMARY TABLES FOR ANALYSES IN WHICH THE FIVE TRANSFORMED COPYING VARIABLES ARE COVARIED

	Source of Variation	DF	MS	F	Significance Level
Stages of drawing the solid cube	Regression	5	50.442	0.380	0.860
	Grade	2	679.400	5.120	0.009
	Sex	1	521.691	3.931	0.053
	Grade x Sex	2	172.189	1.298	0.282
	Error	53	132.702		
Stages of copying the oblique projection	Regression	5	45.040	0.713	0.617
	Grade	2	280.208	4.433	0.017
	Sex	1	397.587	6.291	0.015
	Grade x Sex	2	64.606	1.022	0.367
	Error	53	63.204		
Stages of copying the isometric projection	Regression	5	41.825	0.695	0.630
	Grade	2	245.588	4.079	0.023
	Sex	1	31.825	0.529	0.470
	Grade x Sex	2	35.124	0.583	0.562
	Error	53	60.205		
Stages of drawing the mock-cube	Regression	5	144.849	2.742	0.028
	Grade	2	546.943	10.355	0.001
	Sex	1	244.724	4.633	0.036
	Grade x Sex	2	117.693	2.228	0.118
	Error	53	52.821		

Raw Regression Coefficients

Covariates	Within Cells
AC-RVA	-0.546
AC-AVO	0.104
AC-ACUTE	0.277
AC-OBTUSE	0.132
PARALLEL	-0.145

VII. ANALYSES USING DRAWING STAGE AS THE INDEPENDENT VARIABLE

Special Contrasts:

1 = Stage 1 vs. Stages 2, 3, 4, and 5
2 = Stage 2 vs. Stages 3 and 4
3 = Stage 3 vs. Stage 4
4 = linear trend over all five stages

A. STAGE OF THE CHILD'S DRAWING OF THE SOLID CUBE USED AS THE INDEPENDENT VARIABLE

TEST OF A1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	1.155	6.000	47.000	0.346	0.359

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	1.710	1.165	0.197	0.492
AC-RVA	4.213	320.655	0.045	-1.085
AC-AVO	0.823	202.041	0.369	0.444
AC-ACUTE	0.995	53.331	0.323	-0.110
AC-OBTUSE	0.005	0.718	0.945	0.166
PARALLEL	0.786	5.990	0.380	-0.202

TEST OF A2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.487	6.000	47.000	0.815	0.242

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	0.555	0.378	0.460	0.368
AC-RVA	1.638	124.702	0.206	0.558
AC-AVO	0.620	152.278	0.435	0.141
AC-ACUTE	0.815	43.692	0.371	0.553
AC-OBTUSE	0.148	22.474	0.702	-0.302
PARALLEL	0.145	1.106	0.705	-0.217

TEST OF A3

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.958	6.000	47.000	0.464	0.330

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	2.725	1.857	0.105	0.538
AC-RVA	0.122	9.305	0.728	0.835
AC-AVO	0.675	165.650	0.415	-0.388
AC-ACUTE	0.545	29.187	0.464	-0.396
AC-OBTUSE	1.218	184.531	0.275	-0.317
PARALLEL	0.026	0.196	0.873	0.193

TEST OF A4

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.757	6.000	47.000	0.607	0.297

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	1.401	0.955	0.242	0.762
AC-RVA	0.154	11.691	0.697	-0.552
AC-AVO	0.265	65.778	0.607	0.423
AC-ACUTE	0.282	15.124	0.598	0.453
AC-OBTUSE	0.373	56.506	0.544	0.345
PARALLEL	0.045	0.343	0.833	0.177

O. STAGE OF THE CHILD'S COPY OF THE OBLIQUE PROJECTION USED AS THE INDEPENDENT VARIABLE

TEST OF 01

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.900	6.000	47.000	0.503	0.321

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	0.449	0.306	0.506	0.077
AC-RVA	3.148	239.561	0.082	1.335
AC-AVO	0.137	33.647	0.713	-0.799
AC-ACUTE	0.203	10.902	0.654	-0.356
AC-OBTUSE	0.008	1.164	0.930	-0.064
PARALLEL	0.655	4.995	0.422	-0.189

TEST OF 02

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.880	6.000	47.000	0.517	0.318

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	1.640	1.117	0.206	0.437
AC-RVA	0.010	0.784	0.920	0.269
AC-AVO	0.703	172.660	0.406	-0.423
AC-ACUTE	1.841	98.647	0.181	0.650
AC-OBTUSE	0.590	89.460	0.446	-0.311
PARALLEL	0.882	6.725	0.352	-0.379

TEST OF 03

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.782	6.000	47.000	0.588	0.301

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	1.284	0.875	0.262	0.348
AC-RVA	0.838	63.777	0.364	-0.088
AC-AVO	1.404	344.929	0.241	-0.483
AC-ACUTE	0.784	42.038	0.380	-0.302
AC-OBTUSE	0.247	37.405	0.621	0.337
PARALLEL	2.450	18.681	0.124	-0.509

TEST OF 04

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
1 THROUGH 1	0.597	6.000	47.000	0.731	0.266

	UNIVARIATE F TESTS			STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS
VARIABLE	F(1, 52)	MEAN SQ	P LESS THAN	1
MATCH	1.188	0.810	0.281	0.370
AC-RVA	0.828	63.041	0.367	1.174
AC-AVO	0.073	18.024	0.788	-0.945
AC-ACUTE	0.150	8.015	0.701	-0.330
AC-OBTUSE	0.258	39.135	0.613	-0.206
PARALLEL	0.288	2.198	0.594	-0.056

I. STAGE OF THE CHILD'S COPY OF THE ISOMETRIC PROJECTION USED AS THE INDEPENDENT VARIABLE

TEST OF I1

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
I THROUGH I	0.844	6.000	47.000	0.542	0.312

VARIABLE	UNIVARIATE F TESTS F(1, 52)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS I
MATCH	0.293	0.199	0.591	0.023
AC-RVA	2.904	221.026	0.094	1.363
AC-AVO	0.074	18.211	0.786	-0.846
AC-ACUTE	0.076	4.069	0.784	-0.293
AC-OBTUSE	0.040	6.038	0.843	-0.124
PARALLEL	0.582	4.434	0.449	-0.205

TEST OF I2

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
I THROUGH I	0.946	6.000	47.000	0.472	0.328

VARIABLE	UNIVARIATE F TESTS F(1, 52)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS I
MATCH	4.616	3.145	0.036	0.945
AC-RVA	0.006	0.459	0.938	-0.523
AC-AVO	0.319	78.448	0.574	0.642
AC-ACUTE	0.031	1.672	0.860	0.301
AC-OBTUSE	0.051	7.705	0.822	0.172
PARALLEL	0.442	3.370	0.509	-0.093

TEST OF I3

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
I THROUGH I	1.651	6.000	47.000	0.154	0.417

VARIABLE	UNIVARIATE F TESTS F(I, 52)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS I
MATCH	0.609	0.415	0.439	0.430
AC-RVA	4.028	306.609	0.050	-0.073
AC-AVO	6.695	1644.433	0.013	0.821
AC-ACUTE	0.659	46.035	0.358	0.325
AC-OBTUSE	2.104	318.887	0.153	0.389
PARALLEL	0.358	2.730	0.552	0.222

TEST OF I4

TESTS OF SIGNIFICANCE USING WILKS LAMBDA CRITERION AND CANONICAL CORRELATIONS

TEST OF ROOTS	F	DFHYP	DFERR	P LESS THAN	R
I THROUGH I	1.290	6.000	47.000	0.280	0.376

VARIABLE	UNIVARIATE F TESTS F(1, 52)	MEAN SQ	P LESS THAN	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS I
MATCH	1.236	0.843	0.271	0.193
AC-RVA	1.881	143.165	0.176	1.294
AC-AVO	0.205	50.434	0.652	-1.076
AC-ACUTE	0.623	33.364	0.434	-0.463
AC-OBTUSE	0.255	38.660	0.616	-0.133
PARALLEL	0.438	3.337	0.511	-0.026

APPENDIX H

COMPARISON OF RESULTS FROM PEARSON SCHOOL SUBJECTS WITH RESULTS FROM T. HARRY GARRETT SCHOOL SUBJECTS

I. STAGES OF CUBE DRAWING

II. CUBE AND BLOCK MATCHING

III. CHILDREN'S CUBES SCALE SCORE

TABLE I

STAGES OF CUBE DRAWING

A. Stages of drawing the solid cube

	Grade 1	3	5	Average
Pearson	1.73	2.50	3.19	2.48
T. Harry Garrett	2.04	3.03	3.10	2.78
Average	1.87	2.76	3.15	2.62

Analysis of Variance

Source of Variance	DF	Mean Square	F	Significance Level
Grade	2	23.78	17.36	.01
School	1	2.68	1.96	n.s.
Grade x School	2	1.45	1.05	n.s.
Error	167	1.37		

B. Stages of copying the oblique projection

	Grade 1	3	5	Average
Pearson	2.57	3.30	3.58	3.15
T. Harry Garrett	2.87	3.52	3.53	3.34
Average	2.70	3.41	3.56	3.24

Analysis of Variance

Source of Variance	DF	Mean Square	F	Significance Level
Grade	2	11.44	16.12	.01
School	1	1.06	1.50	n.s.
Grade x School	2	0.48	0.67	n.s.
Error	167	0.71		

TABLE I--Continued

C. Stages of copying the isometric projection

	Grade 1	3	5	Average
Pearson	2.80	2.97	3.00	2.92
T. Harry Garrett	3.00	3.55	3.63	3.43
Average	2.89	3.25	3.31	3.16

Analysis of Variance

Source of Variance	DF	Mean Square	F	Significance Level
Grade	2	2.91	4.77	.01
School	1	9.57	15.68	.01
Grade x School	2	0.80	1.32	n.s.
Error	167	0.61		

D. Stages of drawing the mock-cube

	Grade 1	3	5	Average
Pearson	2.03	3.07	3.81	2.98
T. Harry Garrett	2.74	3.59	3.93	3.48
Average	2.34	3.32	3.87	3.21

Analysis of Variance

Source of Variance	DF	Mean Square	F	Significance Level
Grade	2	32.16	23.05	.01
School	1	8.70	6.23	.01
Grade x School	2	1.25	0.89	n.s.
Error	167	1.39		

TABLE II

CUBE AND BLOCK MATCHING

	Grade 1	3	5	Average
Pearson	2.50	3.23	3.48	3.08
T. Harry Garrett	2.87	3.45	3.37	3.25
Average	2.66	3.34	3.43	3.16

Analysis of Variance

Source of Variance	DF	Mean Square	F	Significance Level
Grade	2	9.38	9.59	.01
School	1	1.04	1.06	n.s.
Grade x School	2	0.88	0.90	n.s.
Error	167	0.98		

TABLE III

CHILDREN'S CUBES SCALE SCORE

	Grade 1	Grade 3	Grade 5	Average
Pearson	4.7	8.8	10.9	8.2
T. Harry Garrett	6.5	10.5	10.9	9.5
Average	5.5	9.6	10.9	8.8

Analysis of Variance

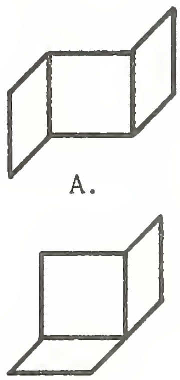
Source of Variance	DF	Mean Square	F	Significance Level
Grade	2	435.98	75.87	.01
School	1	57.21	9.96	.01
Grade x School	2	13.63	2.37	n.s.
Error	167	5.75		

APPENDIX I

SUPPLEMENTAL PROCEDURES

In addition to the tasks described in the procedure section, some other tasks were included at the stage of administration. These were designed to illustrate the representational processes.

The first of these is related to the third experimental issue, the child's capacity for drawing complex two-dimensional configurations. Two additional complex figures, shown in Figure 24, were devised, by rearranging the square and the two parallelograms of which the perspectival cube is composed. Neither of these alternate figures is as compactly constructed as the cube, and hence, as a graphic task, neither one is precisely equivalent to the cube. The question was whether children would copy these figures using three juxtaposed squares. Frequencies for copying the additional complex figures are presented in Table I. While the T. Harry Garrett data were scored using the cube scoring criteria, the Pearson School data were scored with a slightly different set of categories. Therefore, performance of subjects at the two schools cannot be compared directly. However, it is evident that figures composed of three squares were prevalent in both groups and for both stimuli, and that it may be slightly easier to draw parallel diagonal lines when copying these figures than when copying the oblique projection of the cube.



A.

B.

Fig. 24.--Additional complex figures

TABLE I

FREQUENCIES OF USAGE OF DIFFERENT FORMS WHEN COPYING THE ADDITIONAL COMPLEX FIGURES

A. Pearson School

Grade	Figure A			Figure B		
	using predominantly right angles	using diagonal lines	correct	using predominantly right angles	using diagonal lines	correct
1	23	6	1	23	7	0
2	24	6	0	19	11	0
3	19	9	2	20	10	0
4	17	11	4	18	11	3
5	19	5	2	16	13	7
6	11	11	8	5	14	11

B. T. Harry Garrett School

Grade	Figure A			Figure B		
	Stage 2	Stage 3	Stages 4 and 5	Stage 2	Stage 3	Stages 4 and 5
1	8	13	2	5	17	1
3	3	15	11	7	13	9
5	3	9	18	3	10	17

Second, several tasks were included in order to investigate children's concept of the cube. An indication of what concept children use for identifying the cube was obtained by asking each child, after he had copied the conventional perspectival representation of the cube, to name what he had just been drawing. The distinction of interest among the different ways in which children designated the cube was whether or not the name implied volume. From the frequencies in Table II, it is evident that there was not a great deal of change from grade one through six in the names by which the children identified the oblique projection of the cube. To the extent that "block" and "box" both imply volume, well over two-thirds of the Pearson School children appear aware that the drawing does represent a three-dimensional object, which proportion is relatively invariant with respect to age. Lurcat asked the French children to name the oblique projection, and her norms appear in Table II(C) for comparison. Clearly the results of this study do not replicate the trends reported by Lurcat, namely, a shift in older children toward using names which imply volume. Indeed, among T. Harry Garrett subjects the frequency with which the cube was called a "square" increased with age.

Another technique for obtaining some evidence of the associative value of the cube was to present to the child a chart with photographs of different objects on it (see Plate 2). The child was asked to point to pictures which "looked like" the wooden cube, and later to pictures which "looked like" the line drawing of the cube. The objects had been selected to encompass these categories: (a) pictures of cubes or blocks, (b) pictures of a variety of boxes and cartons, (c) perspectival pictures of objects whose general shape is a rectangular solid, for example, a television set, a doghouse, (d) pictures of objects whose general shape is a flat square surface, for example, a flag, a table top, (e) objects of other shapes, for example, a

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TABLE II

FREQUENCIES OF DIFFERENT NAMES USED FOR THE OBLIQUE PROJECTION OF THE CUBE

	A. Pearson School							B. T. Harry Garrett				C. Lurcat's norms					
	grades							grades				classes					
	1	2	3	4	5	6	sum	1	3	5	sum	(1)	(2)	(3)	(4)	(5)	sum
SQUARE	8	7	4	10	9	10	48	6	10	12	28	15	8	1			24
CUBE					1	1	2		1	2	3	5	6	12	21	26	70
BOX	12	12	13	12	11	11	71	12	6	10	28	2	7	8	1		18
ICEBOX	1						1	1			1						
BLOCK	6	8	9	5	7	5	40		11	3	14						
AQUARIUM		1		2			3							3			3
TRIANGLE						2	2	1		1	2						
N=	27	28	26	29	28	29		20	28	28		22	21	24	22	26	

PLATE 2

Picture Matching Task


ANACIN
The Fannie Farmer Cookbook

tin can, a telephone. For children in all six grades, the three most common associations to the cube were the pictures of the solid cube, the alphabet block, and the open carton. On the whole, the television and the radio were the next most popular associations, followed by the Anacin box and the treasure chest. Apparently, then, both (a) perspectival pictures of solid cubes and rectangular solids, and (b) perspectival drawings of various boxes, are conceptually related to a cube. The major change from first to sixth grade was that the younger children were more likely to make a large number of matches, while older children generally made fewer choices. Younger children sometimes included the lamp and the can of tuna fish, for example, which are perspectival pictures of cylindrical solids. They also chose the flag, a flat object whose shape resembles the shape of one face of a cube, more frequently than did the older children. The relevant data are presented in Table III.

Finally, some of the children were asked to draw additional three-dimensional cubes, either the colored cube or the transparent box.

The colored cube is a solid cube whose six sides are each painted a different color. After the child drew a picture of it, he was asked to show where the different colors were in his picture, and he was encouraged to revise his picture, using colored pencils, to show in it all of the information about the cube which he said that he saw. This task was designed (a) to give the experimenter more idea of what the child's drawing represented, (b) to encourage the child to talk about the problem of representing the cube, and (c) to see what sorts of drawings might be prompted from children at different cube drawing stages.

The transparent box is constructed of three-inch squares of plexiglass. The top piece is removable, allowing objects to be placed inside of the box. The task was designed (a) to help explore the width of the child's category of

tin can, a telephone ...

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block, and the ...

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treasure chest ...

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(a) ...

(b) ...

TABLE III

PICTURE MATCHING DATA

Grade	1	2	3	4	5	6	
av. number of pictures chosen	6.4	4.7	7.3	4.5	4.7	3.9	
modal number of pictures chosen	3	3	4	4	4	3	
N=	30	30	6	30	30	29	
Frequency with which each picture was chosen:							sum
cube	29	29	6	30	29	29	152
block	28	25	6	30	29	27	145
carton	28	28	6	27	29	25	143
Anacin box	10	7	2	5	5	3	32
treasure chest	10	2	2	2	4	4	24
cigarette pkgs.	8	5	2	4	3	2	24
Royal Crown	3	3	1	3	1		11
radio	10	11	3	9	11	9	53
TV	16	10	5	15	12	8	66
book	10	4	2	3	4	2	25
doghouse	4	2	2	2	1	1	12
chair	2	3	1	1	2	1	10
table	3	2	1	1	3	3	13
flag	7	5	3	3	3		21
clipboard	1						1
lamp	2	2	1	1			6
tuna can	5		1		1		7
phone	2				1		3
couch	3	2			1		6
clock	4	1			1		6
Scotch tape	1						1
car	2				1		3
shoes	2						2
flower	2						2

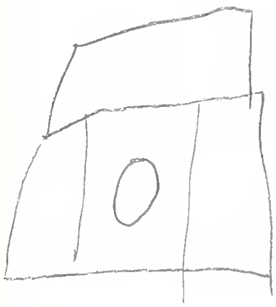
"box," (b) to see if making the hidden lines of a three-dimensional solid visible would affect the child's drawing, and (c) to see how children at different stages of cube drawing would represent containment. The box, along with some typical drawings of it, is shown in Plate 3.

PLATE 3

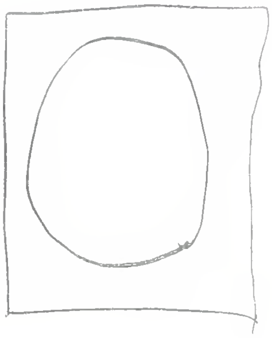
Transparent Box

Above is a photograph of the box. Below are drawings of the transparent box, reduced 4X, by eight different subjects from Pearson School.

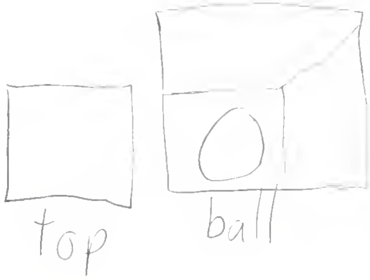
From left, AF, a first grade female,
PC, a second grade female,
LL, a second grade female,
ET, a second grade male;
Second row, VM, a third grade female,
NC, a fifth grade male,
VK, a fifth grade female,
LS, a sixth grade male.



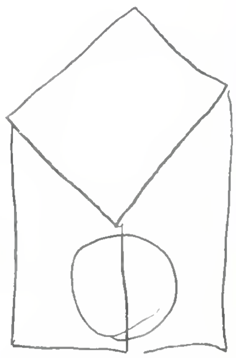
AF



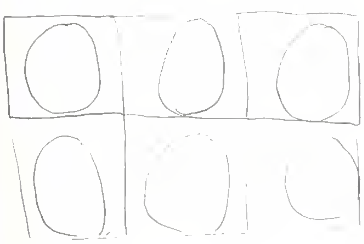
PC



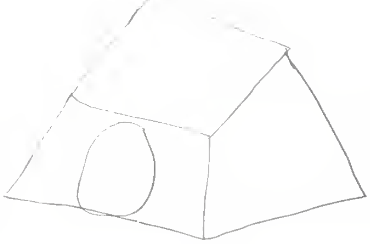
LL



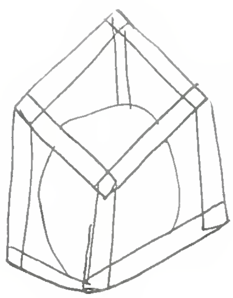
ET



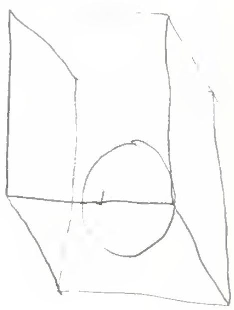
VM



NC



VK



LS

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